THE EFFECT OF SUPERSTRUCTURE MATERIAL ON STRESS DISTRIBUTION IN BONE AROUND IMPLANTS SUPPORTING FIXED PARTIAL DENTURE (IN VITRO STUDY)

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ABSTRACT

BACKGROUND: The biomechanical behavior of dental implants differs from that of natural tooth which results in subsequent complications. The mechanism of stress distribution and load transfer to the implant-bone interface is a critical issue affecting the success rates of implants.

AIM OF THE STUDY: This study aimed to evaluate the difference in stress/strain distribution in the bone surrounding implants resulting from the use of three different superstructure materials using strain gauge analysi

MATERIAL AND METHODS: Polyurethane test block was used as a bone alternative; 2 bone level implants were inserted through a surgical guide into the blocks. Three-unit FDP frameworks were fabricated using three materials: group I: CAD/CAM BioHPP, group II: CAD-CAM zirconia and group III: metal framework FPDs. Vertical occlusal load was applied gradually at a constant rate of 1N per second up to a maximum of 150 N. The resulting strain around Implants was measured by strain gauge device.

RESULTS: The lowest mean (SD) micro-strain value was recorded for group I: BioHpp, followed by group II: zirconia, and the highest mean micro-strain value was found in group III: metal; a statistically significant difference was found between group I (BioHPP) and group III (metal). However, no statistically significant difference was found between group I (BioHPP) and group II (zirconia).

CONCLUSION: Using BioHPP as a more resilient superstructure material had little effect on decreasing the stresses generated around dental implant.

KEY WORDS: Polyurethane test block, BioHPP (high-performance polymer), zirconia, strain gauge analysis.

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INTRODUCTION

The use of osseointegrated implants to support different types of prostheses is a common practice in clinical dentistry today. The high success rates of osseointegrated implants have been well documented in the literature. Implant-supported prostheses are considered a reliable treatment option in case of long span edentulous arches and free end saddle cases (1-3).

Despite their success, many clinical challenges may arise with implants because their biomechanical behavior is totally different from natural teeth. The Osseointegrated implants come in direct contact with alveolar bone, and such an interface is quite unlike natural tooth a nd bone material, so no structural integrity is provided by the normally present resilient periodontium (4-7). Therefore, in implant-supported prosthesis, the stresses are more directly transferred to the bone. This in turn dictates a higher precision in planning, treatment and fabrication of implant borne dental appliances (8,9).

The superstructure material for implant supported prosthesis is a crucial factor affecting stress distribution on implants, as well as other components, retention screws, and adjacent bone tissue. Most of the forces are concentrated at the crest of the ridge, which may result in complications such as bone resorption and loss of implant. As a result, it was suggested that stress-absorbing or resilient materials may be beneficial as superstructures on osseointegrated implants (10).

A variety of framework materials for implant supported prosthesis were proposed throughout the literature starting from the evolution of cast noble or base metal alloys which had excellent strength and longevity, passing through -more recently- the use of modern milled zirconia (11).

Filler reinforced polymer was suggested as an alternative to metal-ceramic and full ceramic restorations in implant-supported fixed partial denture (FPD) as it has lower flexural modulus which allows it to absorb more energy from the masticatory forces (12).

Acrylic resin was first recommended to be used by Branemark, who suggested that the use of acrylic resin for implant-supported prostheses would necessitate some displacement of the periodontium (13).

In 1981, Adell (14) advocated the use of an acrylic-resin occlusal surface for implant prostheses, since their clinical observations had revealed that such an occlusal surface appeared to act as a type of “shock absorber” to buffer excessive occlusal forces (15).

In 1983, Skalak (16) theorized that acrylic resin not only features a much lower elastic modulus than does metal or porcelain, but its use also provides some internal damping. He also postulated that the peak force generated on such an implant by the impact of a particular object during occlusion may be decreased by placing a layer of soft material in the path of the force transmission (17).

Polyetheretherketone (PEEK) is a newly introduced material consists of a high-performance polymer from the polyaryletherketone (PAEK) family.
PEEK is a thermoplastic polymer that can be used as an alternative to metal and zirconia thanks to its strength to weight ratio, biocompatible nature, corrosion resistance as well as shock absorbing behavior (18).
High-performance polymer (BioHPP) is a material based on polyetheretherketone (PEEK), it is a high-temperature semi crystalline thermoplastic polymer which is a relatively new family of polymers, consisting of an aromatic backbone molecular chain, interconnected by ketone and ether functional groups with a density of 1.3–1.5 g/cm3 (19).
The mechanical material properties are very similar to that of the bone skeleton, elasticity of the material which lies within the range of bone, makes it a more natural materials, as it is able to compensate for the torsion and resist tensile stresses particularly in the case of large implant work which need large volumes of prosthetics. In addition, the masticatory forces are therefore cushioned, especially with implant-supported prostheses (20). Besides, the material possess a low plaque affinity, optimal polishability and aesthetic white color making it appropriate for producing high-quality prosthetic restorations (21).

The effect of superstructure material on the stress and strain distribution in the bone surrounding implants remains an area of research and numerous studies were conducted in this area in an attempt to reduce these forces.

The strain gauge analysis was used in the current study to estimate the amount of strain produced around implants by the effect of different superstructure materials. Using strain gauge allows quantitative strain analysis due to their relatively small size, linearity, and minimal interference during testing (22).

Therefore, this in-vitro study was an attempt to evaluate the difference in stress and strain distribution in the bone surrounding implants resulting from the use of three different superstructure materials using strain gauge analysis. The null hypothesis of this study was that the use of different superstructure materials of BioHpp, zirconia and metal show no difference in strain developed in peri-implant bone.

MATERIALS AND METHODS

Preparation of the test model and surgical guide
A single solid rigid Polyurethane Test Block (Sawbones®, Pacific Research Laboratories Inc., Vashon Island, Washington, USA) of (0.32 g/cc) density was prepared, its dimensions were (75 mm) length, (38 mm) width and (52 mm) height. The polyurethane foam block was chosen because it closely resembles the bone mineral density of the posterior maxilla (mean = 0.31 g/cc) according to Devlin et al (23).

Cone beam computed tomography (CBCT) (Vatech Green 16, Vatech®, Hwaseong-si, Gyeonggi-do, Korea.) scan was done for the test block and used with a special software program (OnDemand3D™ App, Cybermed Inc.®, Tustin, California, USA) to design and fabricate a 3D printed surgical guide to ensure placement of 2 implants in correct alignment and parallelism and precisely perpendicular to the upper flat surface of the test block.

The surgical guide was designed to insert 2 parallel implants of (4.0mm) diameter, (12mm) length and with (15mm) distance between the center of the 2 implants allowing (11mm) available space for the pontic between the implants (Fig. 1).
These dimensions were done to be suitable for fabricating a 3-unit implant supported FDP in the maxillary arch with missing two premolars and first permanent molar regarding that the second maxillary premolar is the pontic according to Wheeler’s dental anatomy specifications (24).

The surgical guide virtual design was done by directly modelling on the final virtual test block which was previously scanned with CBCT using (On Demand 3D™App In-Guide module, Cybermed Inc, Tustin, California, USA) and 2 holes were virtually added to the modelled guide according to designed position of the implants and the diameter of the drilling keys which fits perfectly into these holes during the osteotomy procedure.

The surgical guide design was exported to a rapid special dental 3D printer (ENVISIONTEC GMBH, Gladbeck, Germany), then one surgical guide was printed using a specific resin material (E-Shell® 600, ENVISIONTEC GMBH, Gladbeck, Germany) which was used then in fully guiding the implant placement procedure into its predesigned position (Fig. 2).

Implants site preparation and insertion

The surgical guide was centralized on the upper surface of the test block (Fig. 2). Two short anchor pins (provided with the universal drilling kit (In2Guide™ Universal kit, Cybermed Inc.®, Tustin, California, USA)) were screwed to fix the surgical guide properly with the test block and two bone level dental implants of (4.0 mm) diameter (12 mm) length were inserted through the guide to its final position in the polyurethane test block. Then the guide was removed, and implants were tightened with a calibrated torque wrench to 40 Ncm to be flushed with the test block surfa ce level.

Two Titanium non-engaging straight abutments were tightened on both implant fixtures with a calibrated torque driver according to the manufacturer's instructions.

Grouping,

Designing and fabrication of FPD specimens:

The minimal sample size was calculated based on a study of Epprecht A. et al (2018) which aimed to quantify the strain development after inserting implant-borne fixed dental prosthesis (FDP) to various implant–abutment joints (25). A sample size of (8) specimens per group (number of group=3) and total sample size=24 specimens was found enough as statistically significant with 80% power (β=20%) and at a significance level of 95% (α=0.05) (26).

Three different types of materials were used for construction of a total of (24) specimens of 3-unit FDP frameworks and were organized equally into 3 Groups:

Group 1: Eight CAD/CAM BioHPP framework for 3-units FDP.

Group II: Eight CAD/CAM zirconia framework for 3-units FDP.

Group III: Eight metal framework 3-units FDP.

Scanning of the test block with the abutments and implants in place was done with an in-lab optical 3D scanner (smart optics Vinyl®, sm art optics Sensortechnik GmbH, Bochum, Germany)after spraying the abutments with anti glare powder.

A full anatomy FDP was designed using EXOCAD® software, then (1mm) uniform thickness was virtually cut back into anatomical framework. For standardization purpose of all specimens, the same design was used for milling and fabrication of group I: (CAD/CAM BioHPP (breCAM.BioHPP®, Bredent GmbH&Co, Senden, Germany) frameworks) and group II: (CAD/CAM zirconia (PRETTAU® ZIRCONIA, ZIRKONZAHN GMBH, Gais, South Tyrol, Italy) frameworks) specimens, while for group III: (metal frameworks) wax patterns were milled using ZirkonZhan WAX® blank with the same design of other groups, then it was sprued, invested, casted in cobalt-chromium alloy (Mediloy® S-Co, BEGO GmbH, Bremen, Germany), devested and finished according to the manufacturer's instructions.

Fabrication of occlusal loading device

A vertical loading device was fabricated (simulating antagonist teeth in balanced occlusion) to be used in the loading test of the FDP samples (27), as follows:

An opposing mandibular 3-unit FDP was designed using the Exocad® software and occlusal contact points were chosen carefully so that each functional cusp occludes with its opposing fossa (according to wheeler's specifications to normal occlusal contacts in normal dentition) (24).

All contact points were virtually adjusted to touch the opposing simultaneously.

The final design of the opposing mandibular 3-unit FDP (occlusal loading device) was milled using Zirkonzhan WAX® blank, separated from the blank, attached to a base of flat rectangular double layered sheet of modelling wax and finished. Then it was sprued, invested, casted using cobalt-chromium alloy (Mediloy® S-Co, BEGO GmbH, Bremen, Germany) and was finally soldered to a metal base of square cross section to allow its attachment to the loading device in the universal testing machine.

Installation of strain gauges

Four self-protected linear strain gauges (KFG-1-120-C1-11L1M2R; resistance 120.4 ± 0.4 Ω; gauge length: 1 mm; gauge factor: 2.13 ± 1.0%, from: Kyowa El ectronic Instruments Co, Tokyo, Japan) were installed around implants necks on the surface of the test block, one on the buccal side and the other on the palatal sid e of each implant to measure the strain of the crestal area around implants necks (Fig. 3). Strain gauge cyanoacrylate-based adhesive (CC-33A, EP-34B; Kyowa Electronic Instruments Co., Tokyo, Japan) was used to fix the shiny side of the strain gauge to the surface of the polyurethane test block at their designated positions. The terminal wires of all strain gauges were connected to a circuit multichannel strain meter (PCD-300A, Kyowa Electronic Instrument Co., Tokyo, Japan) to record the developed strain. The strain meter was connected to the computer controlling the universal testing machine. The micro-voltage output was converted into micro-strain using software (Kyowa sensor interface PCD 300A; Kyowa Electronic Instruments Co., Tokyo, Japan) to provide a direct reading during loading. All strain gauges were zeroed and calibrated before each loading.

Load application and micro-strain measurement

A fully digitalized universal testing machine (Lloyd instruments LR 5K) was used with the previously fabricated custom-made occlusal loading device adjusted on the occlusal surface of the implant supported FDP framework test specimens.

The previously fabricated custom-made occlusal loading device was attached to universal testing machine (UTS). Occlusal contacts with the opposing occlusal loading device were adjusted in exact opposing position, checked with an 80µ thickness articulating paper (Bausch Articulating Silk 80µ, Bausch Articulating Papers Inc., Nashua, NH, USA) followed by 12µ shimstock-film (Arti-Fol Metallic Shimstock-Film - 12 Microns, Bausch Articulating Papers Inc., Nashua, NH, USA) and the points of contact were visually confirmed and matched to the occlusal points previously designated in the virtual designs of both the test FDP and the opposing occlusal device, and that was done to ensure correct occlusal contacts before loading starts. Vertical occlusal load was applied gradually at a constant rate of 1N per second up to a maximum of 150 N (Fig. 4). The strain meter measured the strain developed and the results were recorded on the computer. Signals corresponding to the strains measured by the strain gauge rosettes and were sent to a data acquisition system and analyzed by the associated software. Each measurement was repeated three times for each specimen, the maximum and minimum principal strains were obtained, allowing at least 5 minutes for recovery. The mean recorded micro-strain values were subjected to statistical analysis.

Statistical analysis of the data

Normality of the data was detected descriptive statistics, plots (histogram and box plot) and Shapiro Wilk test. Quantitative data were calculated as means and standard deviations (SD) for micro-strain (με) as recorded from the strain meter analyzing the mean values of micro strain obtained by the 4 strain gauges (SG) positioned around the 2 implants Buccally and lingually.

One Way ANOVA was applied to compare sarin values between and within the groups and followed by Tukey's post hoc test. Significance level was set (p) value of 0.05. Data were analyzed using SPSS version 25 (SPSS, Inc., Chicago, IL, USA).

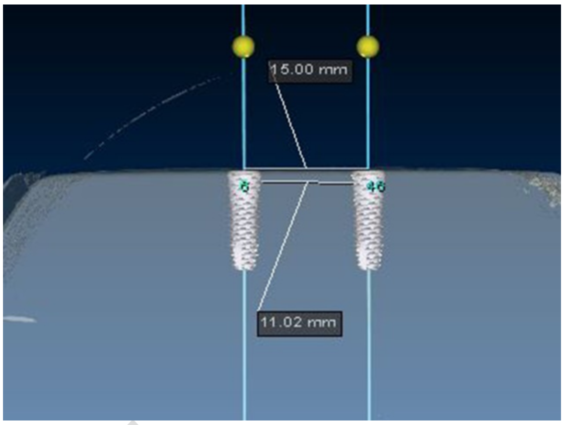

Fig. (1): Planning of the implants position and space in between for surgical guide.

Fig. (2): Final 3D printed surgical guide perfectly fitting on the test block.

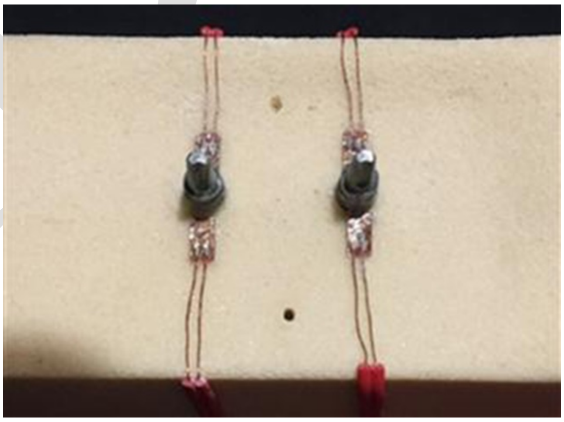

Fig. (3): Four strain gauges (2 for each implant) installed around implants necks on the surface of the test block.

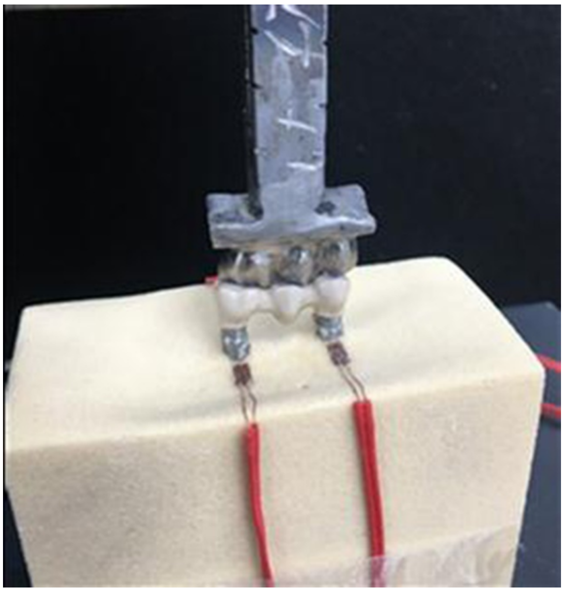

Fig. (4): Vertical occlusal loading of the test specimen FPD framework seated into its position with the previously fabricated occlusal loading device attached to the Universal testing machine.

RESULTS

One way ANOVA was applied for statistical analysis of total mean micro-strain values between group I (BioHpp), group II (zirconia) and group III (metal) frameworks (Table 1,2).

The lowest mean (SD) micro-strain value was recorded for group I: BioHpp (926.88±226.50), followed by group II: zirconia (1175.56±431.82), and the highest mean micro-strain value was found in group III: metal (1513.69±385.21). All these data are presented in (Table 1, Fig. 5).

On comparing between the mean micro-strain values of all 3 groups using the F test, it was found that there was a statistically significant difference (p=0.013, f=5.392).

In addition, a Tukey's post-hoc test comparisons were done between each 2 groups showing no statistically significant difference between group I and group II (p=0.366) or between group II and group III (p=0.168). (Table 2)

Adversely, comparing between group I and group III showed a statistically significant difference (p=0.010) as shown in (Table 2).

Comparison of mean micro-strain values at each strain gauge position between group I (BioHpp), group II (zirconia) and group III (metal) (Table 3, Fig. 6)

SG01 (Buccal Molar) position

The mean (SD) micro-strain value at SG01 (Buccal Molar) position was the highest for group I: BioHpp (1271.25±291.23) followed by group III: metal (1016.88±157.95) and group II: zirconia (745.63±283.07) which was the lowest at this position.

Upon comparing these values for all 3 groups, a statistically significant difference (p=0.002, f=8.733) was found.

SG02 (Palatal Molar) position

The mean (SD) micro-strain value at SG02 (Palatal Molar) position was the highest for group III: Metal (1951.38±686.60) followed by group II: zirconia (1526.88±533.77) and group I: BioHpp (1168.00±546.56) respectively.

Comparing the mean (SD) micro-strain values of all 3 groups at SG02 (Palatal Molar) position a statistically significant difference (p=0.049, f=3.498) was found.

SG03 (Buccal Premolar) position:

The mean (SD) micro-strain value at SG03 (Buccal Premolar) position was highest again for group III: metal (1294.00±632.97) followed by group II: zirconia (819.63±395.17) and group I: BioHpp (282.75 ±100.17) respectively.

Also, a statistically significant difference (p=0.001, f=10.838) was found upon comparing the mean (SD) micro-strain values of all 3 groups at SG03 (Buccal Premolar) position.

SG04 (Palatal Premolar) position

Finally, the mean (SD) micro-strain values at SG04 (Palatal Premolar) position was the highest also for group III: metal (1792.50±383.46) and group II: zirconia (1610.13±649.29) was next, and the lowest mean (SD) micro-strain value was recorded in group I: BioHpp (985.50±374.55) at the SG04 (Palatal Premolar) position.

Again, a statistically significant difference (p=0.008, f=6.064) was found when the mean (SD) micro-strain values of all 3 groups at SG04 (Palatal Premolar) position was compared.

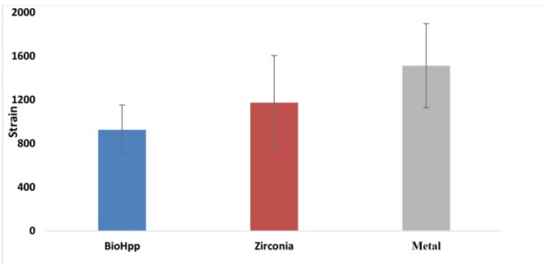

Fig. (5): Micro-strain values between the 3 groups.

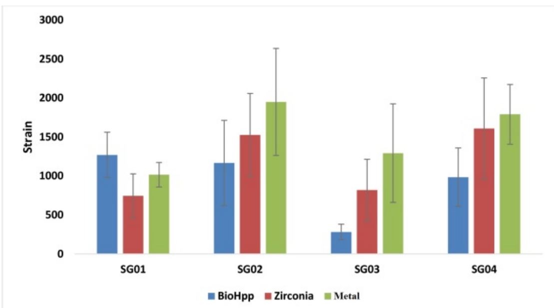

Fig. (6): Strain values at different gauge position between the 3 groups.

Table (1): Comparison of total mean micro-strain values between Group I (BioHpp), Group II (Zirconia) and Group III (Metal) frameworks.

	Group I	**Group II**	**Group III**
Mean (SD)	926.88 (226.50)^{a}	1175.56 (431.82)^{ab}	1513.69 (385.21)^{bc}
f test	5.392		
p value	0.013*		

*Statistically significant difference at p value ≤0.05
^{abc} Different letters denote statistically significant difference between groups.

Table (2): Tukey's Post hoc comparisons of total mean micro-strain values between groups regarding mico-strain values:

Groups	**Compared to**	**p value**
Group I	Group II	0.366
	Group III	0.010*
Group II	Group III	0.168

* Statistically significant difference at p value ≤0.05

Table (3): Comparison of micro-strain values at each strain gauge position between Group I (BioHpp), Group II (Zirconia) and Group III (PFM):

	Group I	**Group II**	**Group III**	**f test**	**p value**
	Mean (SD)				
SG01	1271.25 (291.23)^{a}	745.63 (283.07)^{b}	1016.88 (157.95)^{ab}	8.733	0.002*
SG02	1168.00 (546.56)^{a}	1526.88 (533.77)^{ab}	1951.38 (686.60)^{bc}	3.498	0.049*
SG03	282.75 (100.17)^{a}	819.63 (395.17)^{ab}	1294.00 (632.97)^{bc}	10.838	0.001*
SG04	985.50 (374.55)^{a}	1610.13 (649.29)^{bc}	1792.50 (383.46)^{c}	6.064	0.008*

*Statistically significant difference at p value ≤0.05
^{abc} Different letters denote statistically significant difference between groups

DISCUSSION

This in-vitro study was conducted to evaluate the difference in stress and strain distribution in the bone surrounding implants resulting from the use of three different superstructure materials using strain gauge analysis.

In an attempt to simulate the alveolar bone, polyurethane block was used in the current study simulating other invitro studies (28,29). The use of polyurethane as a bone substitute in strain analysis is a common approach. This material is considered to be linearly elastic, homogenous and isotropic which means that it has identical mechanical properties in all directions (28). Therefore, the polyurethane model eliminates any possible confounding factors related to the biological bone substance (25).

A density of (20 PCF=0.32 g/cc) was chosen for the polyurethane foam block as it closely resembles the bone mineral density of the posterior maxilla (mean = 0.31 g/cc) according to Devlin et al (23).

The strain gauge analysis was chosen for the present study to estimate the amount of strain produced around implants by the effect of different superstructure materials. Using strain gauge allows quantitative strain analysis due to their relatively small size, linearity, and minimal interference during testing (22).

The study was chosen to be in vitro rather than in vivo to allow better control of variables and facilitate the measurements of changes. Besides, in vitro studies are beneficial in providing comparative data with exclusion of variations such as the nature of overlying ridges, the quality of residual bone, strength of masticatory muscles and variation in oral hygiene (30).

The strain gauge analysis test was done using a custom made occlusal vertical loading device. An opposing metallic FDP was designed, fabricated and adjusted to be in balanced occlusion with the sample FDPs. It was made of metallic rather than ceramic or resin material to ensure its stability and accuracy during testing and prevent its breakage or chipping with multiple load applications opposing each test sample. Then it was used as a vertical occlusal loading device during testing the FDP samples. This device was fabricated in order to simulate the combination of forces developed in a natural balanced occlusion scheme in an attempt to get more realistic results of micro-strain developing around implant necks (27).

The experimental design of the study gave a precise control on the load applied (150 N) to the supporting structures and FDPs tested in such a way that it lay within the average clinical levels of the natural biting force (31) without causing permanent visible deformation or destruction of the medium density (20 PCF) polyurethane test block used during testing and load application.

The results of the strain gauge analysis revealed that there was a statistically significant difference of total micro-strain values upon comparing all 3 groups. There was also a statistically significant difference between group I (BioHPP) and group III (metal). However no statistically significant difference was found between group I (BioHPP) and group II (zirconia).

In the current study, the use of rigid (zirconia) or resilient (BioHpp) material as superstructures on implant-supported fixed prosthesis showed similar strain distribution with strain magnitudes, slightly higher in the zirconia group. Both superstructure materials (zirconia and BioHpp) had similar biomechanical behavior in terms of stress distribution in implants and peripheral bone.

Several studies have assessed the effect of using different prosthesis materials on stress distribution in implants and peripheral bone structure and have reported that the change in prosthesis materials does not lead to major differences or has only a minor effect on the stress patterns. The results of the current study are in agreement with the results of those studies (32,33).

The elastic modulus is one of the important factors determining a material’s behavior (34). It is believed that the low elastic modulus of BioHPP FPDs and its resilient nature could contribute to dissipate the impact forces of mastication, absorbing part of the applied loads. On the contrary, most of the forces applied on zirconia FPDs are directly transmitted to the supporting bone because zirconia is not considered a resilient nor a good shock-absorbing material. Some studies found that resin restorations promote better stress distribution when compared with ceramic restorations (35,36).

Kaleli et al stated that, the customized PEEK abutments showed lower stress values within the abutment structure however developed high stress in restorative crowns, considering that the elastic modulus of PEEK is 60 times less than zirconia (37).

Wang et al reported that the amount of transferred energy to the bone interface was the same even when crowns made of different materials showed variable displacements. These biomechanical responses are similar to those observed in our study (33).

On the contrary, the results of the current study disagree with that of Schwitalla et al who claimed that the lower the elastic modulus of PEEK material was found to provide inadequate support and result in more transfer of stresses to the surrounding bone (38).

Although BioHpp is considered an elastic and shock-absorbing material (39), no significant reduction in the stress transferred to bon e was observed. This is explained by the fact that, many factors other than the prosthetic material can affect the amount of masticatory forces transferred to implants and their surrounding bone. These factors include the abutment, the inner screw and the cement layer (32). The amount of energy transferred to the bone interface first passes through the abutment-implant interface (33). Some of the energy transferred is considered to be dissipated through intermediate structures, which may elucidate the same biomechanical responses in implant-bone interface when using different superstructure materials.

Regarding the conventional metal group, strain analysis revealed a statistically significant difference in the total micro strain compared to BioHPP group which agrees with previous studies (40). This may be explained by the higher modulus of elasticity and increased stiffness of cobalt chromium compared to BioHPP.

CONCLUSION

Within the limitation of this study the following could be concluded:

Implant supported BioHPP restorations compared to metal-based restorations has significantly decreased stresses transferred from occlusal forces to the peri-implant bone.

there is no significant difference between BioHPP and zirconia as implant supported FDP restorations on the strains developed around implants.

CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

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