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EVALUATION OF STRESS DISTRIBUTION IN IMPLANT RETAINED FIXED PROSTHESES FABRICATED FROM POLYETHERETHERKETONE (PEEK) AND ZIRCONIA BY CAD/CAM TECHNOLOGY (AN IN-VITRO STUDY)

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ABSTRACT

Introduction: About 90% of implant failures occurs in the posterior region, in association with high occlusal load. The posterior area of the oral cavity presents more occlusal loading than the anterior area with lower bone quality. Materials with low modulus of elasticity and high resiliency were suggested to reduce the occlusal stresses that are transferred to the bone-implant interface in order to simulate the shock absorbing action of the resilient periodontal ligament. **Aim:** Evaluation of stress distribution in implant retained fixed partial posterior prostheses, constructed from CAD/CAM Polyetheretherketone and Zirconia. **Material & methods:** The lower left second premolar and second molar of an acrylic cast were prepared to receive implant supported fixed partial prostheses. Five axis dental milling machine (DWX-52D) was used to mill ten fixed partial denture prostheses. The milled prostheses were grouped into two groups (n=5); group A (zirconia) and group B (PEEK). The strain gauges were attached around each implant mesially, distally, buccaly and lingually. The universal testing machine was used to apply the force at the mid pontic region of each prosthesis. Data were analyzed using Student and Paired t- test at $p \leq 0.05$. **Results:** The highest mean microstrain (με) value was reported with the PEEK samples (3585.3±35.32) and the lowest value was reported with the zirconia samples (988.3±20.05) around the second premolar. The highest mean microstrain (με) value was reported with the PEEK samples (3803.5±21.52) and the lowest value was reported with the zirconia samples (1469.7±26.44) around the second molar. **Conclusions:** Different prostheses materials produce different stress patterns around dental implants.

INTRODUCTION

Successful implant-retained prostheses are based on successful osseointegration; therefore, the material with better biomechanical behavior shows a long term successful osseointegration (1).

About 90% of implant failures occur in the posterior region, in association with high occlusal load, cantilever or bruxism. The posterior area of the oral cavity presents more occlusal loading than the anterior region with lower bone quality (2).

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KEYWORDS

CAD/CAM, PEEK, zirconia, strain gauge, implant, fixed prostheses, posterior bridge.

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Materials with low modulus of elasticity and high resiliency as acrylic resin and composite were suggested to reduce the occlusal stresses that are transferred to the bone-implant interface in order to simulate the shock absorbing action of the resilient periodontal ligament. This suggestion was not supported by finite element analysis (FEA) where clinical failures have been reported with polymers as composite or acrylic. Clinical studies showed fewer complications when the porcelain was used on the same kind of frameworks. Moreover, it has been reported to have a better stress distribution with bending moments using stiffer materials like metals (3, 4).

Zirconia computer-aided design/computer-aided manufacturing (CAD/CAM) implant-supported prostheses are used as an alternative for metal-ceramic prostheses due to their superior mechanical properties, flexural strength and fracture toughness. CAD/CAM implant-supported prostheses fit significantly better and show survival rates comparable to conventionally fabricated prostheses. CAD/CAM technology avoids the unnecessary weakening and alterations of the prosthesis by the laboratory works and ensures the durability of the prosthesis (5).

BioHPP is a material based on PEEK (polyetheretherketone), a tooth-colored polymeric material that has been introduced recently into dentistry. The benefits lie in its resiliency and elasticity of the material, which lies within the range of human bone, making it a more natural material. By another word; PEEK could produce shock absorbing action and reduce the stress transmitted to the supporting implants. PEEK materials are now used to produce fixed and removable prosthesis by using both CAD/CAM technology and pressable technique. PEEK fixed partial prostheses fabricated via CAD/CAM technology was suggested to show a higher fracture resistance than pressed PEEK dentures (6).

A biomechanical analysis of the biting force showed no large difference in the biting forces between subjects having dental implants and subjects with normal teeth. The mean of the biting force in newton (N) for the normal premolar teeth ranged from 276.6 to 289.4 while the mean of the biting force for the premolar teeth after implantation ranged from 277.3 to 286.9. In the molar region; the mean of the biting force for the normal teeth ranged from 330.5 to 344.9 while the mean of the biting force after implantation in the molar region averaged from 314.6 to 322.5. A specially designed transduction device used in this study where the selected patients were asked to apply their possible maximum biting force (7).

The forces applied to the dental implants referred to as vector quantities as they possess directions and magnitudes. Three dimensionally, these forces are not mainly longitudinal forces because they are broken down into their component's parts (fraction parts) within three dominant clinical axis: faciolinugal, mesiodistal and occlusoapical. The process of broken down of the force into the fractions parts called vector resolution. These parts are easily controlled by the implant geometry and the engineering design. Dental implant is subjected to three main types of forces: compression, tension and shearing. The implant-bone interface is maintained by compressive forces, while tension and shear are destructive for such interface; especially shearing forces. Offset loading; especially in multiple abutment restorations result in bending loading that's increase the shearing and tension forces (complex) that may compromise the implant-restoration system. The moment of the force that tend to produce bending or rotation is known as torque or torsional load that develops about the clinical axis and induce stress concentration at the crestal bone and result in crestal bone resorption at the implant bone-interface (8).

When the implant retained prostheses is subjected to occlusal loads; the peri-implant area at the crestal bone and the greatest micro deformation site is defined by the cervical area of the implant. This is independent of the implant and prostheses designs, type of load or type of bone. Above 3000 micro strains were found to be unfavorable for the bone while bone loss is expected above 4000 micro strains. Therefore, loss of osseointegration and bone loss are expected when the stresses exceed the physiologic limits of the bone. The overload level starts with 1500 micro strains while bone fractures at 10000 to 20000 micro strains but 40% of this value trigger bone resorption (4000 micro strains) (9).

The dental implant lacks the periodontal ligament; therefor they react in a different fashion biomechanically to the occlusal forces. The crestal bone represent the fulcrum to the lateral forces and represent the region of stress concentration in the dental implants while the apical part of the root represents a fulcrum to the lateral forces in the natural teeth with the advantage of shock absorbing effect of the periodontal ligaments (10).

The oral rehabilitation with dental implant is biomechanically evaluated by means of strain gauge, finite element analysis (FEA), digital image correlation and photoelasticity or by combination of these methods. The stress in the prosthesis, implant and teeth can be assessed in vivo & in vitro; under static and/or dynamic loads by the strain gauge technique (11).

The strain gauge consists of a resistor with a wired conductive that is attached by a glue to the structure to be tested that undergo changes in their electrical resistivity under applied forces. It provides a numerical measurement that can be statistically analyzed (12).

The strain gauge can be used in the following areas: embedded in the resin, on the outer surface of a fixed or removable prostheses, on implant abutments, on a non-threaded surface of implant body, the bone immediately adjacent to the neck of an implant (13).

Due to the limited availability of studies investigating the outcome of PEEK material on stress distribution of implant retained fixed partial dentures, the current study was conducted to compare the stress distribution between PEEK and Zirconia implant supported CAD/CAM fixed partial dentures.

It is hypothesized that the peri-implant strains would be reduced when using PEEK implant supported screw-retained fixed partial posterior bridge rather than using zirconia prostheses.

MATERIALS AND METHODS

This study was approved by the research ethical committee of Faculty of Dentistry, Suez Canal University (n.115 /2018).

Working cast preparation:

The mandibular left first and second premolars, first and second molars teeth were removed from a ready-made complete dentulous acrylic model. An impression was taken for the modified ready-made acrylic model using addition silicone elastomeric impression material (Lascod, Italy). The impression was poured by cold cure clear acrylic resin (Acrostone, Egypt) (modulus of elasticity 4.4 MPa) to produce the working model.

A 3D printed surgical guide was constructed to align and insert the titanium implants (3.9 mm in width and 11 mm in length with an internal hex) into their positions parallel to each other.

The acrylic working model was scanned by by J.Morita Veraview x800 CBCT Machine (J.Morita Japan) using the cast scanning function. DICOM files were then exported from the I.Dixel software and imported into the BlueSky Plane software (BlueSkyBio, USA) where the files were converted into STL model on which the surgical guide design was done. The implant positions were designed at the second premolar and the second molar area.

Fabrication of the fixed partial prostheses:

Twenty titanium abutments (TUT, Egypt) (straight abutments) were screwed to the two implants (each two abutments at a time) and then scanned by Shera 3D desktop laser scanner (Shera 3D, Germany) to obtain an optical impression. Then, the STL file of the optical impression was transferred to a desktop computer utilizing the computer assisted design technology (CAD) to form a 3D working model.

One selected anatomical fixed partial prosthesis design from the exocad library (DentalCad 3.0 Galway) was applied for all scanned abutments. Five axis dental milling machine (DWX-52D) was used to dry mill ten fixed partial prostheses from two different materials (5 fixed partial prostheses from katana zirconia (HTML) disc (Kurary Noritake, Japan) (group A) and 5 fixed partial prostheses from BioHPP PEEK disc (Bredent, Germany) (group B). The zirconia prostheses were sintered at the temperature 1500 ºC for two hours according to the manufacture recommendations. Finally, zirconia and PEEK prostheses were finished and polished according to the manufacture's recommendations.

Strain gauges attachment:

Strain gauges (kyowa, Japan) of 1 mm length, 2.13±1.0% (gauge factor), and 120.4±0.4Ω (gauge resistance) were attached around each implant mesially, distally, buccally, lingually using cyanoacrylate adhesive (Epobond, Egypt). All strain gauges were arranged in series to form a Wheatstone bridge.

Bonding of the specimens:

MKZ primer (Bredent, Germany) was used for conditioning of the abutments and the zirconia retainers while the Visio. Link primer (Bredent, Germany) was used for conditioning the peek retainers which were light cured for 90 seconds in the Bre. Lux power unit curing device (Bredent, Germany) (wavelength range 370 nm – 400 nm).

DTK adhesive (Bredent, Germany) was used to bond the zirconia and peek fixed partial prostheses to the implant's abutments. The conditioned implants abutments were screwed to the implants and the screw channels were sealed with dental wax (Cavex, Netherlands) (each two abutments at a time). Then, the adhesive was injected at the fitting surface of each zirconia and peek retainers and pressed onto the abutments that were screwed to the implants (each two abutments with one specimen at a time). The adhesive was chemically cured for three minutes for each zirconia and peek fixed partial prosthesis.

Force application and strain measurement:

Each strain gauge was connected to a digital multichannel strain meter device (koyawa PCD 300A) that was connected to a desktop computer to register and collect the microstrains transmitted to each strain gauge.

Each fixed partial denture was screwed to the working model implants using the fixations screws and the screwdriver (TUT, Egypt). Then, the buccolingual (4 strain gauges) and the mesiodistal (4 strain gauges) strains were recorded separately for each specimen as the strain meter contains only 4 channels.

A universal testing machine (Lloyd LR5K, UK) with a rounded head rod of 1.3 mm diameter was used to load the implant retained fixed partial prostheses with a functional load of 300 N at a crosshead speed of 1 mm/min at the mid pontic region. Each specimen was loaded twice to record the bucco-lingual and the proximal microstrains separately. The strain indicator was allowed to recover to zero strain before each reloading (Figure 1).

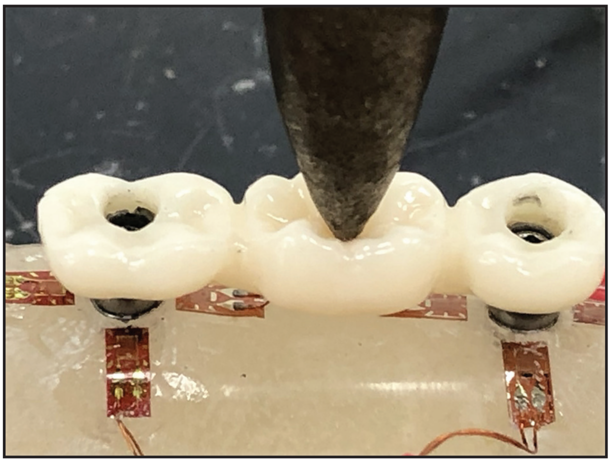

Fig. (1) Force application on one zirconia fixed partial denture

Statistical analysis:

Statistical analysis using Student t-test and Paired t-test with a statistical significance of P-value ≤ 0.05.

RESULTS

Around the second premolar, there was a statistically significant difference between both groups (P<0.001). Group B had a higher mean microstrain value (3585.3 ± 35.32 με) than that of groups A (988.3 ± 20.05). (Table 1).

Table (1) *Means and standard deviation (SD) of microstrains (με) recorded around the second premolar by PEEK and zirconia fixed partial prostheses*

	N	Mean	SD.	p
PEEK	**5**	**3585.3**	**35.32**	**<0.001****
Zirconia	**5**	**988.3**	**20.05**	

p: p value for Student t-test.
**: Statistically significant at p ≤ 0.05*

Around the second molar, there was a statistically significant difference between both groups (P<0.001). Group B showed a higher mean microstrain value (3803.5 ± 21.52 με) than that of group A (1469.7 ± 26.44). (Table 2).

Table (2) *Means and standard deviation (SD) of microstrains (με) recorded around the second molar by PEEK and zirconia fixed partial prostheses*

	N	Mean	SD.	p
PEEK	**5**	**3803.5**	**21.52**	**<0.001****
Zirconia	**5**	**1469.7**	**26.44**	

p: p value for Student t-test
**: Statistically significant at p ≤ 0.05*

DISCUSSION

The posterior implant retained prostheses are subjected to the highest levels of forces more than any other areas inside the oral cavity with subsequent possible failure chances due to mechanical overloading of the implant retained prostheses. The structure of the prosthesis material has a great effect upon the stress distribution behavior and load transfer to the bone-implant interface; therefore, affecting the success rate of the prosthesis supported by two implants (2,14,15).

In the current study, the working model was constructed from a solid rigid acrylic resin to simulate the human cancellous bone as it shows a consistent and a uniform mechanical property similar to human cancellous bone (16,17,18).

In order to standardize and control the accuracy of the implants placement, a 3D printed surgical guide was constructed in order to control the drill location, angulation and depth of both implants. The surgical guide was made from a rigid transparent to allow easier observation of the drills through the clear working model material and to be to be stabilized in its position during drilling (19).

In the present study, implants with internal hexagon type were used as it provides better mechanical stability than the external hexagon type. The internal hexagon implant-abutment connection demonstrates lower levels of stress than the external hexagon implant-abutment connection (20).

In order to standardize the prostheses design constructed from the two different materials, CAD/CAM technology was used for the prostheses construction to avoid the alterations of the prostheses by the laboratory works. Furthermore; CAD/CAM implant-supported prostheses fit significantly better comparable to conventionally fabricated prostheses(5).

For samples of this study to be identical, all the abutments and the working model were scanned by the Shera 3D laser desktop scanner, and all CAD/CAM zirconia and peek fixed partial dentures were designed using the same software exocad (DentalCad 3.0 Galway) and milled by In lab DWX-52D milling machine to get ten identical fixed partial dentures.

The biomechanical evaluation in this research was conducted by the use of strain gauge technique, which represents the only biomechanical method that can evaluate the implant retained prostheses extra-orally and intra-orally. The strain gauge technique is the only biomechanical method that can obtain a direct numerical measurement from the structures being tested that can be statistically analyzed. Strain gauge analysis started to be used in the laboratory research of the dental implant rehabilitation system only after proving in vivo efficiency in the term of comparing different prostheses materials and their impact upon the bone behavior (21,22).

In the current study, the strain gauge sensors were attached at the peri-implant area around the implants neck since the stress concentration area and the greatest micro deformation (strain) site is found at the cervical region of the implant (9,13).

The applied load was selected to be 300 N which represents the average value of the biting forces at the posterior region of the oral cavity in both fully dentate individuals and in partially edentulous patients. In order to standardize load application; a load of 300 N was applied with a round stainless-steel ball at the central fossa of the pontic of each sample of both groups of the tested materials (7).

There has been a wide variation in the cross-head speed employed for testing the fixed partial dentures. In the present study, the selected cross head speed was 1 mm/min. This was accepted in other studies testing 3-units fixed partial dentures reported by (23, 24, 25).

In the current study, screw fixation was used rather than cementation to attach each fixed partial denture to the working model implants. Screw fixation allows easier handling of the superstructures without damaging or altering the implants and the working model (25).

In the current study, zirconia implant-retained fixed partial prostheses had the lowest values of the peri-implant strains while PEEK implant-retained fixed partial prostheses had the highest values of peri-implant strains with statistically significant difference at each location of the strain gauge sensors, which means better stress distribution in zirconia superstructure material than PEEK superstructure material. This might be explained by the mechanical properties of the superstructure materials where zirconia has high modulus of elasticity and low resiliency while PEEK has much lower modulus of elasticity and higher resiliency(6,26).

Rigid materials demonstrate less strains and exhibit much less bending moments than non-rigid materials that will deform easily under loading by their higher resiliency during masticatory forces; thus, creating lateral forces and higher stresses at the implant-bone interface and lesser load transferred through the rest of the superstructure. If the superstructure material is truly rigid, there should be no harmful horizontal load components but only vertical load components. If the superstructure material is not rigid enough, there will be a horizontal load component that will increase under high loading conditions and strong biting forces resulting from bending moments that can harm the osseointegration. Stiffer materials show higher stress concentration in the prosthetic framework and transmit lower stress levels to the implants, screws, abutments and the bone than soft materials. The increased stiffness of the implant retained prostheses material contributes to a superior transfer of the loads toward the supporting implants (22,27-36).

CONCLUSION

Within the limitations and conditions of this in vitro study, it was concluded that the zirconia fixed partial prostheses had a superior effect on the stress distribution when compared to PEEK fixed partial prostheses.

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