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COMPARISON OF STRAIN DEVELOPMENT OF IMPLANT SUPPORTED THREE UNITS FIXED PARTIAL DENTURES FABRICATED FROM ZIRCONIA AND PEEK "IN-VITRO STUDY"

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ABSTRACT

Statement of the Problem: selection of prosthetic materials is a critical factor affecting the long-term success of implant supported restorations. PEEK poly-ether-ether ketone-is a quite new polymer used for dental applications. However, there are limited data available concerning Stress analysis and strain development of PEEK restorations as implant superstructure. Introduction;

Materials and Methods: A total of 14 frameworks (n=7) were fabricated of Zirconia and PEEK by milling technique, divided into two equal groups to be randomly seated on its corresponding titanium abutment and then subjected to 5000 thermo-cycles. Strain gauge method was selected in this study to assess strain development where strain gauges were adhesively bonded mesial and distal to each implant-abutment unit and data were recorded using a strain meter device.

Results: As regards the overall strain (mean of the four channels): there was no statistically significant difference between the two groups.

Conclusion: PEEK frameworks revealed slightly higher strain compared to zirconia with o significant difference in the over-all strain channels.

KEYWORDS: implant, PEEK, strain, Fixed

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INTRODUCTION

Implant supported restorations are used more commonly for replacing missing teeth due to great technologies and recent modifications added to the field of implantology. Implants offer an option that is providing a way of stiff anchorage in bone through osseointegration mechanism. [1-3]

Implant supported restorations are subjected to higher occlusal loads directly reaching bone due to lack of periodontal ligaments in natural teeth and their shock absorbing quality and proprioception. [4-10]

Various materials are used to produce implant supported fixed partial dentures with multiple fabrication methods. [4]

The use of Metal fused to porcelain bridges to restore long span regions especially posteriorly is somehow problematic in terms of bending and deflection . [10,11]

Selection of supra-structure material is a crucial issue since it has a great impact on forces transfer to the whole prosthetic components (implant/ implant-abutment and bone implant interface), if these forces were magnified, it might end up with marginal bone loss or even worse.

Material properties is directly related to its load bearing capacity which is essential when planning for restoring teeth. [1,10] Stresses transfer is greatly dependent on many factors as bone quantity and density, implant design and surface topography, and the prosthesis type. Success of implant supported restoration is correlated to bone-implant interface integrity with implant/prosthetic components. [15,17,18]

Despite not providing ultimate esthetic quality in comparison to glass-based ceramics but they have high fracture strength when used as restoration over an implant, yttria-stabilized tetragonal zirconia polycrystalline (Y-TZP) is used nowadays mainly as an implant supported fixed partial dentures due to its superb mechanical properties such as fracture resistance and flexural strength. Zirconia as a restoration have gained its popularity due to its high flexural strength (ranging from 900-1200 Mpa) comparable to steel and hence the terminology ‘‘ceramic steel’’. [5,6]

Beside chipping of veneering material as a common drawback, Aging of zirconia presents as low temperature degradation (LTD) have detrimental effects on its mechanical properties and it is related to exposure to wet environment or even water vapor for an extended period of time. Zirconia degradation is accompanied by tetragonal to monoclinic phase transformation leading to surface uplift of grains and greater stresses that might initiate the cracks along the grain boundaries. [13,18,30]

Bacchi et al investigated the influence of superstructure material and vertical misfits on the stresses created in an implant-supported partial prosthesis. They concluded that, stiffer materials promote greater stress concentration in the framework, and that this increases proportionally with the increase of stiffness of the material. [24]

PEEK (poly-ether-ether-ketone) as an alternative new material had been introduced since 1978. It is a semi crystalline, thermoplastic, synthetic, high performance aromatic polymer. It is white (natural beige), rigid material and have great thermal stability up to 335.8° C. [35–37]

It showed resiliency up to 1200N of chewing forces. It is non allergic with a low plaque affinity. Flexural strength of PEEK is 140- 170 MPa, density up to 1300 kg/m3 and thermal conductivity 0.29 W/mK. Young’s modulus of PEEK (modulus of elasticity) is 3-4 GPa which is close to human bone, enamel and dentin. This polymer is resistant to hydrolysis and it is non-toxic. It also showed high wear-resistance and high biocompatibility. However, like any other polymer, PEEK overheating might have a harmful effect on it. [35]

Modifications were made to improve PEEK’s properties. Bio-HPP is an example of modified PEEK containing 20% inorganic nano ceramic fillers (0.3 to 0.5 μm grain size). BioHPP’s (bioactive High-Performance Polymer) very small grain size of its ceramic fillers adds constant homogeneity which is essential to reach consistent quality. BioHPP use for rehabilitation cases could reduce peak masticatory forces from lateral movement, leading to more durability for the restorations. BioHPP's framework reported bond strength is 25 MPa, flexural strength is >150 MPa, melting range up to 340°C and hardness (HV)=110. BioHPP if used as a framework material offers a lot of advantages like: lighter weight restorations, shock absorbing effect, metal free restorations, less material fatigue, low plaque affinity and no corrosion. [3,46]

Yadel et al studied wear and fracture strength of zirconia- based ceramics and metal-supported ceramics after chewing simulator treatment, using Katana, Prettau, Zenostar, InCoris TZI, BruxZir and porcelain fused to metal (PFM) (n=10). All samples were thermal-cycled. Fracture resistance was higher in zirconia except for katana group samples that showed the lowest values. [47]

Rodríguez et al investigated both the fracture load and fracture pattern of prosthetic frameworks constructed out of different materials produced using CAD/CAM technology. Thirty standardized specimens with two abutments were fabricated to receive three-unit FDP frameworks. Specimens were divided into three equal groups (n=10) based on the material, group 1: milled metal, group 2 zirconia and group 3 for (PEEK). All specimens were subjected to thermocycling and fracture resistance test using the universal testing machine at a cross head speed: 1 mm/min). Axial compressive load was applied at each pontic's occlusal surface. The metal frameworks group exhibited the highest fracture load values while PEEK group recorded higher fracture load values than zirconia ones. Clinically acceptable fracture load values greater than 1000 N were recorded for all groups. PEEK as material might be considered as an upcoming alternative for posterior FPDs fabrication. [20]

Nobre et al [21] investigated the outcome of full-arch rehabilitation by a fixed implant-supported PEEK prosthesis with the all-on-4 theory. Less rates of marginal bone loss were observed thanks to the shock absorbing quality of PEEK frameworks. Minimal or no bone loss around implants with minimal complications in the first year was also reported by AL-Rabab'ah et al [22]

Thus, the aim of the study is to evaluate and compare strain development of three units' implant-supported fixed partial dentures fabricated from PEEK and zirconia.

Objectives

Thus, the aim of this study is to evaluate and comoare strain development of three-unit implant supported fixed partial dentures fabricated from zirconia and PEEk

MATERIALS AND METHODS

Materials

The following materials have been used in the present study: All materials brand names, descriptions, manufactures and their lot number are listed in Table (1)

TABLE (1) List of brand names, material descriptions, manufactures and lot numbers used in this study

Brand	Material description	Manufacture	LOT #
PEEK	Bio-Hpp PEEK blank Shade: white	breCAM. BioHPPTM; Bredent GmbH & Co.KG, Senden, Germany	482047
Zirconia	HT CAD/ CAM blanks	Aconia zirconia, China	20180921
Implant analogue	Titanium implant analog	ROOTT dental implants, Switzerland	JHR3AN
Implant Abutment	Straight titanium abutment	ROOTT dental implants, Switzerland	JIO1A1N
Strain guage	1mm strain gauge	KYOWA company, Japan	Y4537s

Methods

Zirconia and PEEK three-unit frameworks were CAD/CAM designed and constructed to be seated on implant abutments in an epoxy resin block simulating a case of missing mandibular first premolar and first molar teeth. Strain gauges were fixed mesial and distal to the implant abutment interface to evaluate both strain development.

Sample size calculation: Based upon the results of Karl et al [23], the computed effect size for induced strains was found to be (1.7), using alpha (α) level of (5%) and Beta (β) level of (20%) i.e power = 80%; the minimum estimated sample size is a total of 14 specimens (7 specimens per group). Sample size calculation was performed using IBM ® SPSS® Sample Power ® Release 3.0.1 §

Sample grouping: For this study, 14 three units implant supported fixed partial dentures were divided into 2 groups each group having 7 samples as follow.

A) Group1: (n=7) of monolithic zirconia implant supported frameworks.

B) Group2: (n=7) of monolithic PEEK implant supported frameworks.

14 frameworks were milled and divided into two equal groups according to the type of the selected material (n = 7)

Auto-polymerizing epoxy resin was poured in a mold box and left for ten minutes to ensure bubbles escape after vibration where Two implant analogs (12 mm in length and 4 mm in width) were held using milling machine surveyor F (Fig. 1) with a 14 mm distance between center of each implant using a ruler based on natural teeth model.[61,62] to get a rectangular epoxy resin base.

After 4 days the mold was removed, and the block was checked for bubbles. Then Two straight titanium abutments (3.5 mm in its external diameter and 2.1 mm internal diameter) were tightened to 35Ncm using implant system's tightening screw over each implant analog following the manufacturer's recommendations [26] as shown in Fig (2)

Scanning: A desktop 3D dental scanner (DS-Mizar) was used for scanning each titanium abutment after being sprayed with 3D scanning spray [28].

The EXOCAD software parameters were set for each group.

For zirconia group each framework was designed as follows: 50 μm virtual cement space, 0.5mm uniform all over thickness, 3x3 mm^2 connector area cross section ($9mm^2$) based on manufacturer's recommendations. [6,25–27] Fig (3)

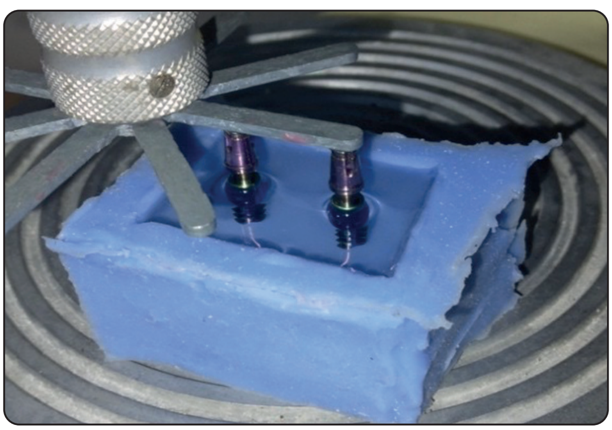

Fig. (1) Epoxy resin poured around each implant held by milling machine surveyor.

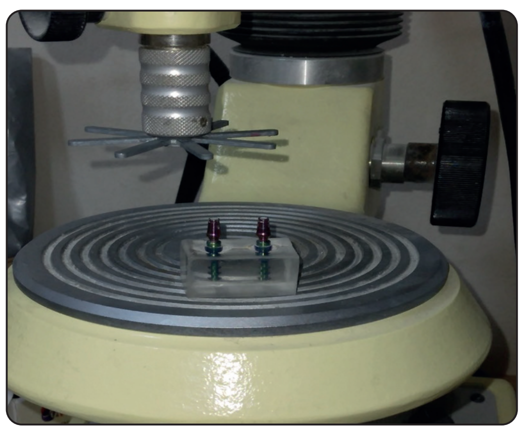

Fig. (2) Epoxy resin block with 2 embedded implants and titanium abutments

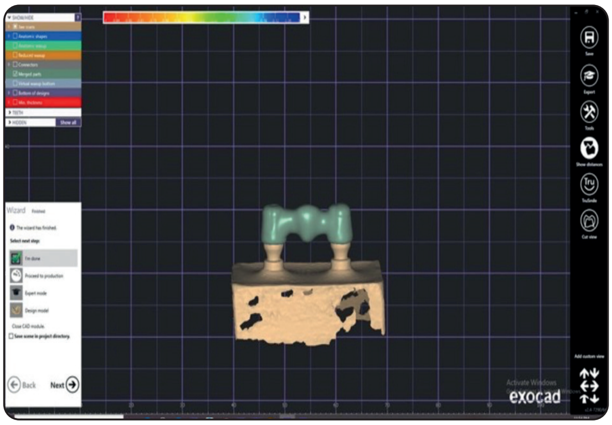

Fig. (3) Exocad software showing zirconia framework final design.

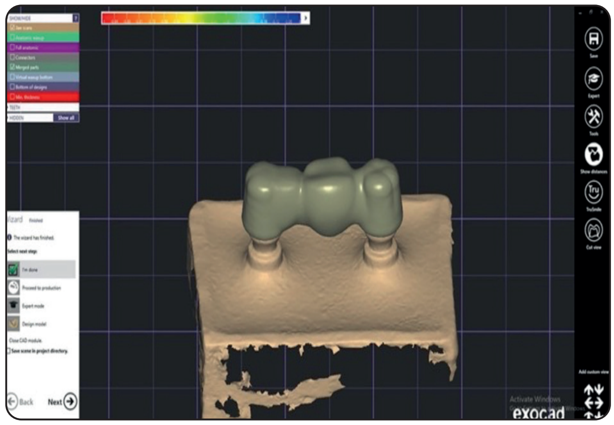

Fig. (4) Final PEEK framework virtual design on the exocad software.

The PEEK group was designed with a 4x4mm2 connector area cross section (16mm^2), 0.7mm uniform all over thickness and 50 µm virtual cement space using CAD/CAM system and following manufacturer's recommendations. Fig (4) After being approved, those details were sent in the form of (STL) file to the milling machine to start choosing appropriate blank type and thickness.

Each milled pre-sintered zirconia framework was heated using a high temperature furnace following the manufacturer's instructions. The furnace was programmed for an increase in temperature from 25˚C up to 1550˚C at a rate of 15˚C per minute.[22] A long cooling phase was provided which allowed temperature drop from 1550˚C to 150˚C while 10 hours cooling phase was employed. 60 Specimens were removed from the sintering furnace and allowed to bench cool to room temperature.

Thermocycling

Each specimen before testing underwent 5000 thermal cycles (equivalent to 5-6 months inside patient mouth) in distilled water.[49] Between 5˚C and 55˚C to simulate intra-oral temperature fluctuation. Dwell times were 25 seconds in each water bath* with a lag time 10 s. The low-temperature point was 5˚C while the high temperature point was 55˚C.[28 ,32]

Strain development measurement

Preparation of strain gauge bonding site (Mesial & Distal to the implant fixture) was performed by abrading the epoxy resin model with silicon carbide abrasive paper in a gradual manner (P400, P600, P800) to get a flat surface, then it was wiped clean with acetone to get rid of any dust which might affect strain readings. [18] Each electrical strain gauge was positioned mesial and distal to each implant abutment assembly, was bonded tangentially to each implant platform on the resin block just below implant abutment interface and fixed to the surface of the epoxy resin model using strain gauge adhesive (cyanoacrylate resin) Fig. (5) [1,9,23,24] Strain gauges used were 1 mm in length, with a 2.13±1.0% gauge factor, and a 120.4±0.4-gauge resistance. Active Strain gauges were used to measure strains induced

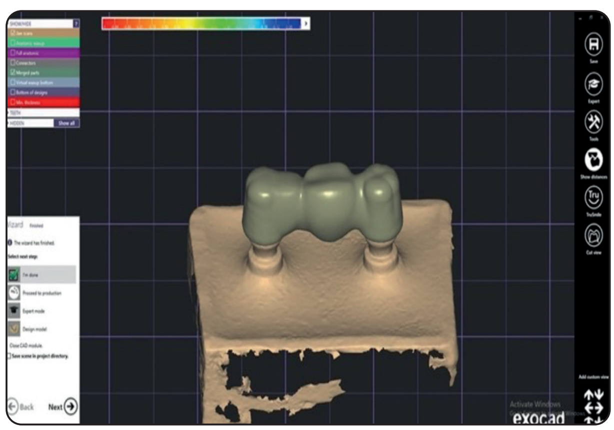

Fig. (5) Strain gauges bonded to epoxy resin model.

around implants after load application. Strain gauges measure the change in resistance and then calculate the amount of strain at the site of attachment. [23,24]

Strain gauges were left for 24 hours to ensure its complete setting. The lead wire from each strain gauge was connected to a device called four Channels strain-meter [Kyowa Electronic Instruments Co., Ltd, Tokyo, Japan] Fig. (6) to record dynamic resin model micro strains transmitted to each strain gauge from the moment of load application till failure occurred. [9,24,29] A computer device was connected to the strain-meter to record the output signal of each model surface. Nexegen version 4.3 Software was used for data acquisition.

Each strain gauge was set at (zero), numbered to facilitate results reading. [34] A gradually increasing functional load of (200N) maximum was applied with a speed of 0.5mm/min to the pontic occlusal surface as an axial compressive load by a computer controlled universal testing machine [Model LRX-plus; LIoyd Instrument Ltd, Fareham] Fig. (7) from metallic load applicator (70 mm in length and 3 mm tip diameter) for 30 seconds duration until reaching requested load, then the load was removed and any residual strains were released. [18] When the load was completely applied, strain readings were recorded using the strain-meter. Allowing the strain indicator to recover to zero strain before reloading was mandatory. Those readings were averaged, and the range was noted to assess recording system reliability. [24]

Statistical analysis

Numerical data were explored for normality by checking the distribution of data and using tests of normality (Kolmogorov-Smirnov and Shapiro-Wilk tests). Strain data showed non-normal (non-parametric) distribution while fracture resistance data showed normal (parametric) distribution. Data were presented as mean, standard deviation (SD), median and range values. For non-parametric data; Mann-Whitney U test was used to compare between the two groups. For parametric data; Student's t-test was used to compare between the two groups.

Fig. (6) Four channels strain meter.

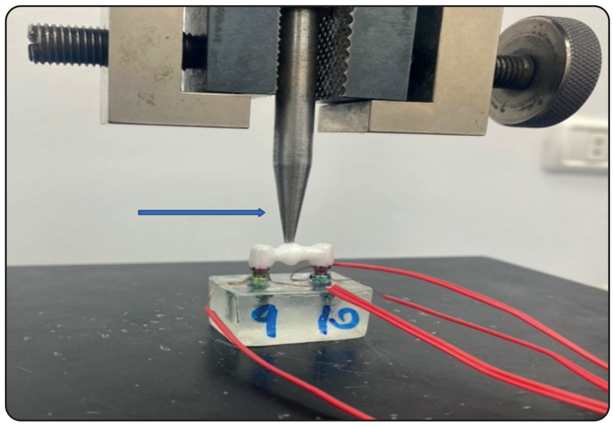

Fig. (7) Load applicator from Universal testing machine on pontic's occlusal surface

The significance level was set at $P \leq 0.05$. Statistical analysis was performed with IBM SPSS Statistics for Windows, Version 23.0. Armonk, NY: IBM Corp.

Numerical data were explored for normality by checking the distribution of data and using tests of normality (Kolmogorov-Smirnov and Shapiro-Wilk tests). Volume loss data showed non-normal (non-parametric) distribution. Data were presented as median, range, mean and standard deviation (SD) values. Kruskal-Wallis test was used for comparison between three groups. Dunn's test was used for pair-wise comparisons when Kruskal-Wallis test is significant. The significance level was set at $P \leq 0.05$. Statistical analysis was performed with IBM SPSS Statistics for Windows, Version 23.0. Armonk, NY: IBM Corp.

Table (2) Strain results at M1, D1, M2 as well as D2 channels for zirconia and PEEK restorations

Channel	Group	Median	Min	Max	Mean	SD	*P*-value	Effect size *(d)*
M1	Zr	440	315	705	469.6	103.5	0.006*	**0.696**
	P	845	62.5	2105	813.6	575.9		
D1	Zr	210	25	685	232.2	159.5	<0.001*	**0.953**
	P	295	60	1125	445.4	334.5		
M2	Zr	280	70	380	254.2	89	0.011*	**0.635**
	P	321.3	160	445	310.4	95.4		
D2	Zr	335	207.5	1105	432.3	237	0.025*	**0.555**
	P	526.3	171.3	1430	654.3	404.1		
Overall	**Zr**	**317.5**	**259.1**	**469.3**	**331.1**	**52.4**	0.466	**0.175**
	P	**419.1**	**414.3**	**822.5**	**417.8**	**239.2**		

: Significant at $P \leq 0.05$

RESULTS

Comparison between groups

At M1, D1, M2 as well as D2 channels: zirconia samples showed statistically significantly lower strain induced than PEEK samples as shown in table (2) and Fig (8), (P-value = 0.006, Effect size = 0.696), (P-value). As regards the overall strain (mean of the four channels): there was no statistically significant difference between the two groups (P-value = 0.466, Effect size = 0.175).

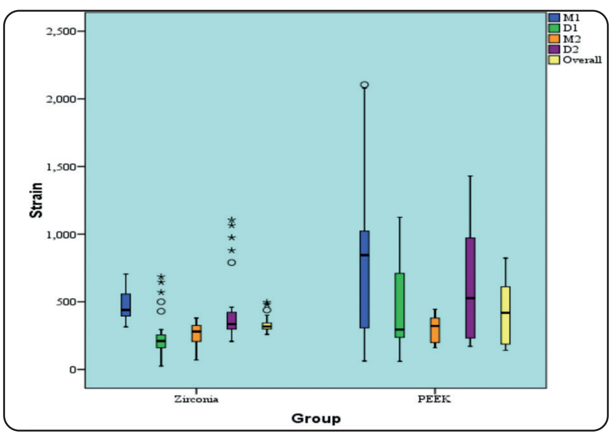

Fig. (8) Box plot representing median and range values for strains induced in the two groups.

DISCUSSION

Dental implants as an example offer the privilege of being a conservative option restoring lost teeth side by side with being a functional option can rely on for replacement of missing teeth. Higher survival rates, being biologically acceptable and matching each patient's esthetic demands make implants and its superstructure a first choice. [49] Implants' high success rate depends not only on successful Osseo integration, but also on the harmonious integration of a prosthesis into the dental arch. [36]

This study was performed in-vitro as clinically, several factors such as implant inclination, impression technique and load application methodology can complicate the testing process and deviate the results from the ideal situation, so the in vivo measurements are much more difficult than in vitro ones. [37]

In implant- supported fixed partial dentures, any stresses occur as a result of functional forces are transmitted to the supporting bone by its restorative material, abutment, and implant. In contrary to teeth- supported fixed partial dentures, stresses which are transmitted to the supporting bone by the restorative materials can be maintained by periodontal ligament tissue acting as a shock-absorber. [37]

Load transfer from implants to surrounding bone depends on multiple factors, one of it is the prosthesis type. It's a crucial issue to select a material for fabrication of fixed partial denture. [37] Selection of a material for implant supported restorations is more critical as it has a great impact on how stresses may transfer to the whole system affecting the long- term clinical success and implant prosthesis stability. Stresses during function can be transferred to each prosthetic component as the implant itself, bone-implant interface and implant-abutment connection.[1]

Biomechanical behavior analysis is an important implication for implants to do their job or not. Failure to apply the occlusal forces in accordance with the real scenarios might affect stresses at the implant- prosthesis junction. There are several methods to evaluate stress, strains, and displacement for dental implant analysis. In experimental tests strain measurements give reliable results only at the specific position of the indicator. [38]

Strain development around implant supported restorations is a critical factor. The use of strain gauges is one of the methods used to assess strain levels in relation to bone-implant assembly. This methodology simulates the clinical situation of transmission of forces generated on the prosthesis during function and then transmitted to the implant and surrounding bone. It's also used to assess the biomechanical behavior of implants. The application of this method is based on electrical resistance, either in vivo or in vitro under static or dynamic loads. These resistances are very sensitive and assess the type of deformation of the area where they are fixed. [39]

The selection of epoxy resin material was to simulate bone matrix properties since it has mechanical properties comparable to those of trabecular bone (Young's modulus reaching 3000 MPa). [9,20,24,25] Moreover, reaching a level of standardization, eliminating any chance for premature destruction and eliminating the chance for different bone types of quality. [20]

Mechanical strain distribution is an important factor to reach long term implant success. [40] In this study strain gauges were adhesively bonded mesial and distal to each implant just below implant-abutment interface to detect variable levels of strains upon subjected to a predetermined applied load through a universal testing machine load applicator. [9,24,29] The resin block flat surface facilitated bonding and adequate positioning of each strain gauge. [9] The same bonding criteria was adopted by many authors [40,41] unlike other studies where strain gauges were bonded to implants, metal framework [42] and even to the abutment. [43]

Strain readings

Zirconia showed statistically significant lower strain induced than PEEK group, as regards to the mean strain of the four channels individually. Regarding overall strain, there was no statistically significant difference between both groups. Pair wise comparisons revealed that M1 showed the statistically significant highest strain. While D2 showed statistically significant lower value. There was no statistically significant difference between M2 and D1 channels; both showed the statistically significantly lowest strain values. Position of strain gauge fixation below implant abutment interface is directly related to high strain readings in M1, D2 channels compared to M2, D1 which were under the pontic area. This may be attributed to high torque stress.

Strain readings around zirconia frameworks were explained by Mascarenhas et al [44] who attributed that higher modulus of elasticity of superstructure material allowed for a more uniform stress distribution within the framework, providing a more efficient and reliable load transfer to the implants. PEEK frameworks recorded higher strain values than zirconia which can be attributed to PEEK's flexibility and resiliency leading to greater stress concentration and more absorption for applied loads energy. [45]

PEEK higher stress concentration comes in agreement with a study conducted by Tretto et al [46] in which 3-D models were used to simulate the clinical condition of maxillary central incisor replacement by implants, with a 100 N applied load in a perpendicular direction. Study results showed that (PEEK) abutments led to higher stress concentration in the implant and at peri-implant bone tissue due to the material less rigidity. Moreover, Campner et al [47] adopted FEA to compare the mechanical performance of three-unit FPDs fabricated from different materials and reached a conclusion that PEEK could alleviate the stress concentration in FPDs. Neim et al [48] also reported increased strain values accompanied with PEEK three-unit FPD which were assumed to PEEK's superior capacity to absorb force through an elastic irreversible deformation due to the material favorable modulus of elasticity.

CONCLUSION

PEEK frameworks revealed slightly higher strain compared to zirconia with no significant difference in the over-all strain channels. Mesial surface of anterior superstructure and distal surface of posterior superstructure showed greater strain compared to distal surface of anterior superstructure and mesial of the posterior, adjacent to the pontic in implant supported fixed dental prosthesis for both zirconia and PEEK.

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