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Prosthetic design and restorative material effect on the biomechanical behavior of dental implants: strain gauge analysis

Efeito do desenho protético e do material restaurador no comportamento biomecânico de implantes dentários: análise de extensometria

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ABSTRACT

Objective: The purpose of this *in vitro* study was to evaluate the effect of different implant prosthetic designs with two restorative materials on biomechanical behaviour using strain gauge analysis. **Material and Methods:** 6 different screw-retained implant restorations were designed and fabricated using a CAD/CAM system. These implants were divided into three main groups according to each design: group FB (fixed bridge); CB (cantilever bridge); SC (separate crowns). Each group was divided into two subgroups according to their restorative material: subgroup I – ultra translucent multi-layered zirconia (Kuraray Noritake Dental Inc, Japan); subgroup II – a combination of PEEK framework (BioHPP, Bredent, GmbH & Co.KG, Germany) and zirconia crowns (ultra-translucent multi-layered zirconia, Kuraray Noritake Dental Inc, Japan). Each subgroup was subjected to a vertical load of 100 N and their biomechanical behaviour was evaluated using a strain gauge (Kyowa, Japan) with a resistance of 120 Ω, length of 1 mm and width of 2.4 mm. For the implants, two strain gauges were positioned buccally and lingually, parallel to the long axis of the implant. For the restoration, two strain gauges were positioned buccally and lingually in the middle of it. The results were analyzed using three-way analysis of variance (ANOVA), followed by serial two-way and one-way ANOVAs at each level of the study, followed by Tukey's post hoc test P-values were adjusted for multiple comparisons using BENFORRONI correction and the significance level was set at $P \leq 0.05$ for all tests. **Results:** FB showed the lowest strain values out of all 3 design groups. Moreover, the combination of PEEK and zirconia showed strain values smaller than full zirconia. The highest mean strain value was recorded in CB at 299.50 while the lowest mean strain peak value was recorded in group FB (74.50). The highest strain peak was recorded in CB subgroup I (3901.0 ± 195.91) and the difference had statistical significance (P-value < 0.01). **Conclusion:** the fixed bridge designed with PEEK framework and zirconia crowns was found to be more favorable in restoring the posterior edentulous area regarding strain measurements on the level of prosthetic components, implant and bone level.

KEYWORDS

Biomechanics; Dental implants; CAD/CAM; Dental prosthesis; Milling machines.

RESUMO

Objetivo: O objetivo deste estudo *in vitro* foi avaliar o comportamento biomecânico de diferentes desenhos protéticos com dois materiais restauradores em implantes dentários usando análise por extensometria. **Material e Métodos:** 6 diferentes restaurações parafusadas em implantes foram projetadas e fabricadas usando um sistema CAD/CAM. Esses implantes foram divididos em três grupos principais de acordo com cada desenho: grupo PF (ponte fixa); PC (ponte cantilever); CI (coroas individuais). Cada grupo foi dividido em dois subgrupos de acordo com o material restaurador: subgrupo I – zircônia multicamada ultra translúcida (Kuraray Noritake Dental Inc, Japão); subgrupo II – uma combinação de estrutura PEEK (BioHPP, Bredent, GmbH & Co.KG, Alemanha) e coroas de zircônia (zircônia multicamada ultra translúcida, Kuraray Noritake Dental Inc, Japão). Cada subgrupo foi submetido a uma carga vertical de 100 N e seu comportamento biomecânico foi avaliado usando um extensômetro (Kyowa, Japão) com resistência elétrica de 120 Ω, comprimento de 1 mm e largura de 2,4 mm. Para os implantes, dois extensômetros foram posicionados pela vestibular e lingual, paralelos ao longo eixo do implante. Para a restauração, dois extensômetros foram posicionados no centro da estrutura, pela vestibular e lingual. Os resultados foram analisados usando análise de variância de três fatores (ANOVA), seguida de ANOVA dois fatores e um fator em cada estágio do estudo, seguidas pelo teste de Tukey. Os valores P foram ajustados para comparações múltiplas usando a correção de BENFORRONI e o nível de significância foi estabelecido em P ≤ 0,05 para todos os testes. **Resultados:** PF apresentou os menores valores de deformação de todos os 3 grupos de desenho. Além disso, a combinação de PEEK e zircônia apresentou valores de deformação menores do que a zircônia total. O maior valor médio de deformação foi registrado no PC em 299,50, enquanto o menor valor médio de pico de deformação foi registrado no grupo PF (74,50). O maior pico de deformação foi registrado no subgrupo PC I (3901,0 ± 195,91) e a diferença teve significância estatística (P-valor < 0,01). **Conclusão:** a ponte fixa projetada com estrutura de PEEK e coroas de zircônia mostrou-se mais favorável na restauração da área edêntula posterior em relação às medidas de deformação dos componentes protéticos, implante e nível ósseo.

PALAVRAS-CHAVE

Biomecânica; Implantes dentários; CAD/CAM; Prótese dentária; Fresadoras.

INTRODUCTION

Implants exhibit biomechanical behaviors different from natural teeth because the of lack periodontal ligaments and the direct contact with bone. Consequently, occlusal loads received by the implant are directly transferred to the surrounding bone structure [1].

Moreover, as the implant-bone interface shows less resilience or no micromovement, its concentrated the load and may cause bone resorption and subsequent the implant failure. Therefore, extreme stress concentrations should be avoided. Resin-based restorative materials may reduce the stress on implants and peripheral bone [2,3].

A key factor for the biomechanical predictability of implant protocols is the development of implants and prosthesis designs capable of providing stability under masticatory standard loading . However, the complex design of the implants and their relationship with the supporting tissues and prosthetic restoration prevent the use of simple evaluation tools to determine the effect of external loading on the internal stresses and displacements [4].

A variety of implant prosthetic designs in addition to materials have been suggested in dental research, yet there is no clear consensus on the proper selection of restorative material and ideal prosthetic design [5,6].

Many complications, which are related to an excessive load being transmitted to an implant, can occur and may be related to the number and location of implants in the arch. These complications suggest that the excessive force is being dissipated in the bone surrounding the implant. As well as the number of implants [7], the type of connection between the abutment and implant is an essential parameter to evaluate the biomechanical behavior, both the internal and external connections. Campaner et al. [8], concluded that the number of implants directly influenced the distribution of strain using Photoelastic and Strain Gauge Analyses.

On the other hand, Mozayek et al. [9], discussed the effectiveness of adding a supporting implant in stress distribution of long-span fixed partial dentures using three-dimensional finite element analysis. The study concluded that adding a supporting implant has no mechanical advantages, whereas it has the disadvantages of complicating treatment and the complications that may occur to the implant and surrounding bone itself.

In the presence of cantilevers, clinical reports and retrospective analysis' have been published where complications such as implant fracture, prostheses loosening, debonding, and abutment screw damage have arisen [10]. Leading the authors to believe that cantilever extensions need to be accounted for when considering prostheses design. Dogus et al. [11], even suggests an alternative design using an engaging abutment furthest from the cantilever to provide a mechanical advantage with increased resistance to fracture of the distal abutment screw [11-14].

Studies have suggested that occlusal overload may contribute to implant bone loss or loss of osseointegration of successfully integrated implants. Rani et al. [16], compared peri-implant strain developed in different types of implant-supported prostheses i.e, screw-retained splinted, and non-splinted. The study concluded that splinted crowns produce less peri-implant strain when compared to non-splinted crowns [15,16].

Excessive load transmitted to the implant should be avoided for the achievement of long-term results. Complications associated with excessive load may occur as the load on the implant is then dissipated within the peri-implant bone. The stress or energy transfer between implant and peripheral bone is affected by biomechanical factors such as the direction of loading and the number of implants. In addition, the prosthetic design and material characteristics of the implant or restorative crown are of paramount significance [17,18].

Monolithic zirconia has been introduced with great success showing superior strength, low fracture probability, excellent antagonistic wear characteristics and outstanding aesthetics [19]. In many cases, with increased prosthetic interocclusal distance a fixed full-arch implant prosthesis can be used. This type of prosthesis replaces the clinical crown of the missing teeth and utilizes a pink-colored resin material to replicate the soft tissue. Advancements in fabrication technology allow the fabrication of hybrid prostheses consisting of a substructure replacing lost soft tissues and bone, covered with aesthetic ceramic crowns [20].

The ongoing research for a material with physic-mechanical properties similar to those of natural tooth structure opened the way to the development of a new generation of high-performance polymers. A recently introduced high-performance polymer, namely Polyetheretherketone (PEEK), poses excellent physical properties and mechanical shock absorbing properties with high biocompatibility attention in many applications [21].

Datte et al. [22], investigated stress distribution in dental implants related to different restorative materials to assist clinicians in deciding the most suitable restorative materials. The study found that materials with high elastic modulus are able to decrease the stress values in the abutments, implant and peri-implant bone.

Biomechanical behaviour of different implant prosthetic designs and materials have been evaluated using several techniques such as photoelastic stress analysis, strain-gauge analysis, mathematical calculations and finite element stress analysis [23]. While finite element stress analysis and strain-gauge analysis are commonly used, strain-gauge analysis is able to precisely record the deformation of any object subjected to stress by evaluating microstrains and elastic deformation stress in prostheses, implants, and peri-implant bone both *in vivo* and *in vitro* [24,25].

Anéas et al. [26] used strain gauge analysis to determine the influence of angulation and vertical misfit in the evaluation of micro-deformations around implants. The study found that the micro-strain was higher for angled implants, yet no correlation was found between the vertical misfit and the strain values.

To date, there is no agreement in literature about the ideal prosthetic design or restorative material that should be used for optimally restoring multiple implants in the posterior edentulous area with the reduced strain during loading. Thus, the purpose of this study was to assess the effect of three different implant prosthetic designs and two ceramic materials on biomechanical behavior of implant-supported fixed birdges.

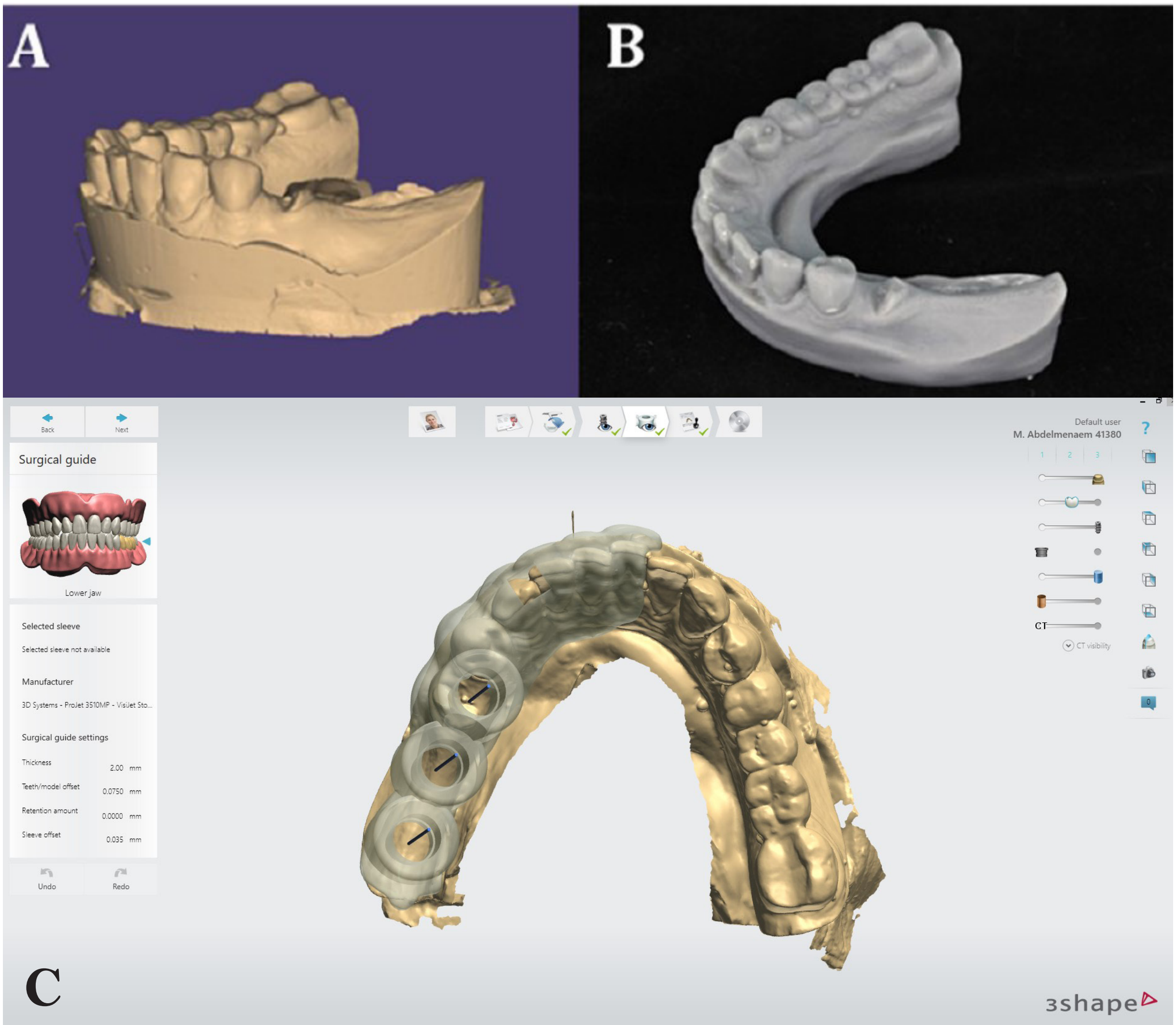
The null hypothesis was that different implant prosthetic designs and ceramic materials would not affect the biomechanical behavior on the level of prosthetic components, implant and bone level.

MATERIAL AND METHODS

A 3-D printed model simulating the mandibular bone was fabricated using a surface scan STL file of a lower partially edentulous posterior jaw (Figure 1). The model was fabricated using resin material with isotropic characteristics and Young modulus (192.98 MPa) similar to human bone [27].

Using the cone-beam computed tomography file, a virtual prosthetic implant design was created. 3D implant planning software was used to position (3 tioLogic®) implant fixtures with a diameter and a height of 3.7 * 9.0 mm, 4.2 * 9.0 mm and 4.2 * 9.0 mm respectively selected from the library. These implants were then virtually placed in the model parallel to each other according to bone level and the prosthetic treatment.

A 3D printed implant-guided with the corresponding metal sleeves was fabricated to ensure the accurate implant placement. Then, implant drilling procedures were performed using the implant guide kit protocol. Initial drilling was done using the pilot drill and primary sleeve, followed by the final depth and position adjustment using consecutive drills, then Fully guided mounting of the first, second and third implant was done, guided by secondary metallic gauges (Figure 2).



Selected sleeve
Selected sleeve not available

Manufacturer
3D Systems - ProJet 3510MP - VisiJet Sto...

Surgical guide settings
Thickness 2.00 mm
Teeth/model offset 0.0750 mm
Retention amount 0.0000 mm
Sleeve offset 0.035 mm

Figure 1 - A) Virtual model, B) 3D printed model and, C) virtual surgical guide.

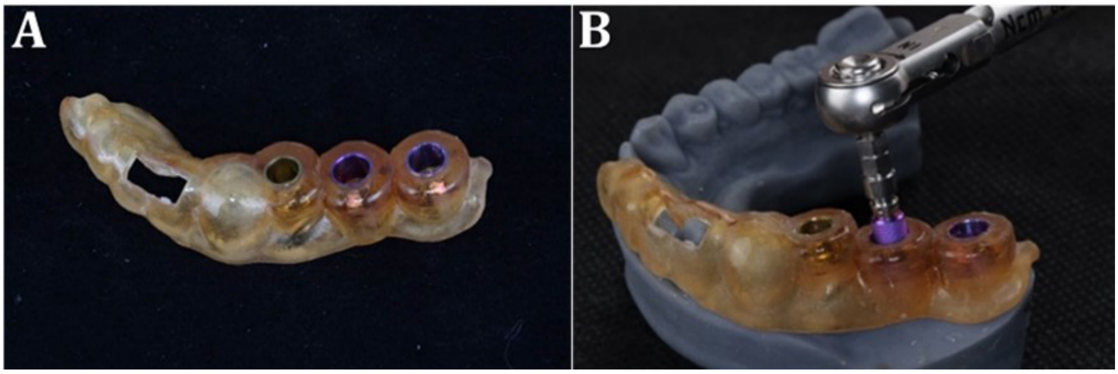


Figure 2 - A) 3D printed implant surgical guide and B) Guided implant placement.

A scan of the model using a desktop scanner (Ineos x5, Sirona Dentsply, Bensheim, Germany.) with scan bodies attached to the fixtures was done to transfer the three-dimensional implant position to the CAD software. The automatic cement gap of 60 microns was selected. For this study, 3 prosthetic designs and 2 material combinations were created with implant screw channels through the occlusal surface. They were divided into 3 groups according to prosthetic design: group FB represents an implant-supported 3 unit fixed bridge; group CB represents an implant-supported 3 unit cantilever bridge; group SC represents 3 implant-supported single crowns. Each group was then divided into 2 subgroups according to the material used. Subgroup I consisted of full anatomical zirconia and subgroup II consisted of a combination between PEEK framework and zirconia crowns.

The fixed PEEK framework, cantilever framework and the 3 separate PEEK copings with thimble cut back were manufactured then covered with zirconia crowns as shown in Figure 3

After checking fitting and proper adaptation, the titanium (Ti) bases were cleaned in an ultrasonic bath using 99% isopropanol for 3 minutes. The bonding areas were then sandblasted with 50-micron aluminum oxide at a pressure of 2.5 bar at a distance of 10 mm while covering the emergence profile with wax. Zirconia restorations were ultrasonically cleaned in 99% isopropanol for 3 minutes as recommended by the manufacturer, then sandblasted with 50-micron aluminum oxide at 2 bar pressure at 10 mm distance for 30 seconds, followed by primer and resin cementation to Ti bases. PEEK frameworks were surface treated with sulphuric acid followed by an application of an adhesion primer and a resin cement both to the underlying Ti base and covering zirconia crowns respectively.

Retention to the physical model was done under 20 N.cm torque in their respective implants, then the screw access channels were blocked by Teflon tape.

For strain gauge measurements, two strain gauges were positioned buccally and lingually parallel to the long axis for each implant at their places in the bone model. For the restorations, two strain gauges were also placed buccally and lingually in the middle area of each restoration, as shown in Figure 4.

All specimens were tested 3 times by being loaded vertically with a perpendicular load of 100 N applied for a period of 10 seconds on the central fossa of their occlusal surfaces using a universal testing machine (Zwick Z010, Zwick GmbH & Co, Ulm, Germany). A custom-made metal Jig designed and fabricated with 3 rounded terminals was used to apply the load located in the central fossa of each crown with a crosshead speed of

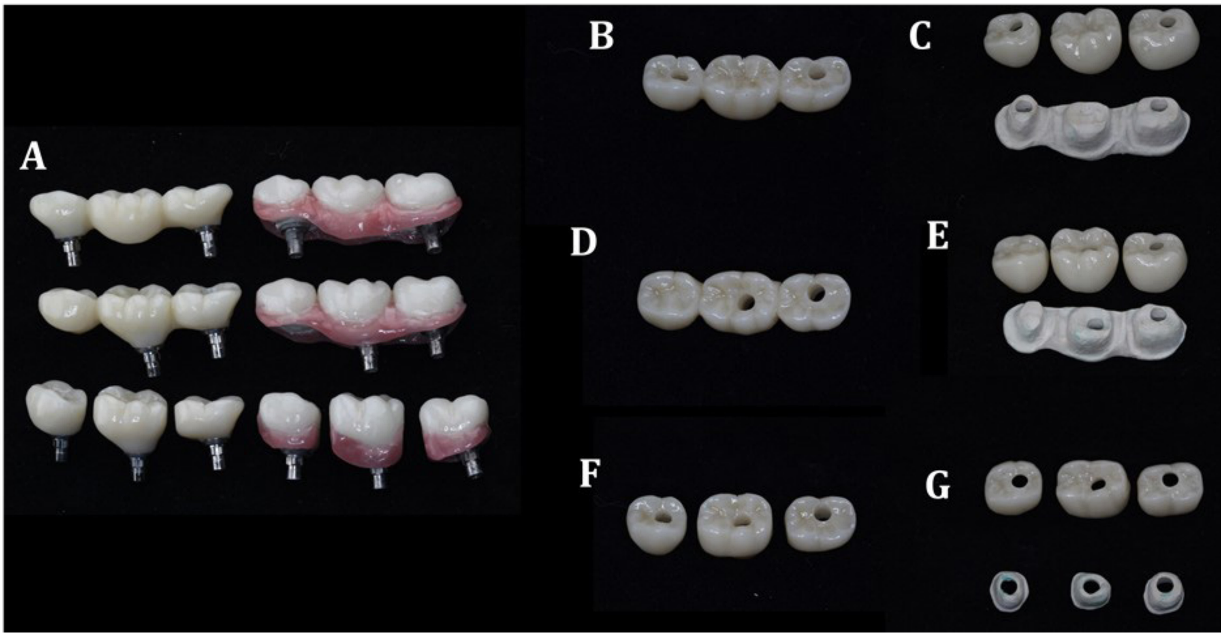


Figure 3 - A) Restorations; B) Group FB-I, full anatomical zirconia fixed bridge; C) Group FB-II, combined PEEK & zirconia fixed bridge; D) Group CB-I, full anatomical zirconia cantilever bridge; E) Group CB-II, combined PEEK & zirconia cantilever bridge; F) Group SC-I, full anatomical zirconia separate crowns; G) SC-II, combined PEEK & zirconia separate crowns.

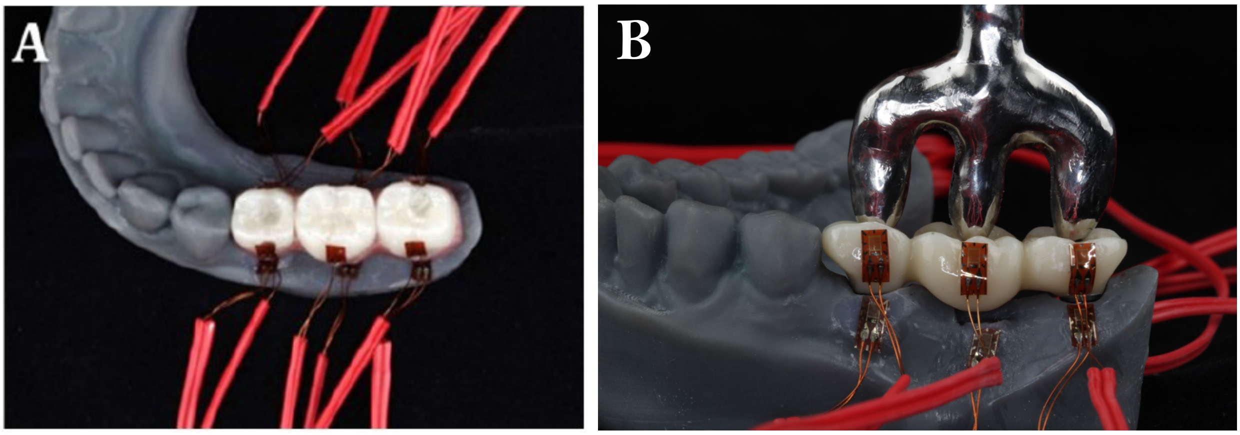


Figure 4 - A) Lingual & buccal, model & restoration strain gauge. B) Vertical load application on restoration and model.

Table I - Factorial analysis

Design Material	Fixed Bridge FB	Cantilever bridge CB	Single crowns SC	Total
Full anatomical zirconia (I)	Group FB, I N=5	Group CB, I N=5	Group SC, I N=5	N=15
Combined PEEK & zirconia (II)	Group FB, II N=5	Group CB, II N=5	Group SC, II N=5	N=15
Total	N=10	N=10	N=10	N=30

Table II - Effect of different designs of implant restorations on crowns and model micro strain (μm/μm) regardless of material type

	Group I (Fixed bridge)	Group II (Cantilever bridge)	Group III (Separate crowns)	Test value•	P-value	Post HOC analysis		
	Mean ± SD	Mean ± SD	Mean ± SD			P1	P2	P3
Total C	74.50 ± 20.47	299.50 ± 26.81	105.50 ± 47.81	6.037	0.007	0.003	0.662	0.010
Total M	2096.50 ± 736.44	5258.00 ± 3152.51	4377.00 ± 1758.64	5.883	0.008	0.003	0.024	0.363

Mean and Standard deviation (SD). •One Way ANOVA test. **P1:** Comparison between subgroup I and subgroup II; **P2:** Comparison between subgroup I and subgroup III; **P3:** Comparison between subgroup II and subgroup III.

0.05 mm/min. Micro strain average values were taken in bone and restorations, this was then repeated 5 times and the mean was recorded.

The sample size according to Factorial analysis as shown in Table I was calculated on Med Calc program version 11.3.0.0. According to a previous study done by Al-Zordk et al. [28], analyzed the impact of microthreads on the stress generated in peri implant bone surrounding zirconia and titanium implants.

Strain gauge measurements were done by a single trained blinded operator for standardization. Data were presented as mean and standard deviation (SD) values. Repeated measure using three-way analyses of variance (ANOVA) was used to compare the tested groups and followed by serial two-way and one-way ANOVAs at each level of the study. P-values were adjusted for multiple comparisons using BENFORRONI correction and the significance level was set at $P \le 0.05$ for all tests. Statistical analysis was performed with IBM® SPSS® (SPSS Inc., IBM Corporation, NY, USA) Statistics Version 25 for Windows.

RESULTS

Results showed that the effect of prosthesis design has significance (P-value < 0.01) on microstrain in crowns and models regardless of the material type as shown in Table II.

The cantilever design had higher microstrain values than the separate-crowns design regardless of the material. The difference was statistically significant (P-value < 0.01). The separate-crowns design had higher microstrain values than the fixed bridge design regardless of the material.

The difference was statistically significant (P-value < 0.01).

Results showed that the effect of design has significance (P-value < 0.01) on microstrain in crown and model regardless of the material type. With highest microstrain in crown and model with cantilever design regardless of the material. The difference was statistically significant (P-value < 0.01), as presented in Table III.

Results showed that the effect of material type has significance (P-value < 0.01) on microstrain, in crown and model. Full Zirconia (ZR) fixed bridge design had higher crown microstrain values than PEEK & Zirconia, with the difference being statistically significant (P-value < 0.01). Full ZR had higher microstrain values than PEEK & ZR, with the difference being statistically significant (P-value < 0.01), as shown in Table IV.

Full ZR cantilever bridge had higher microstrain values in the crowns than PEEK & ZR, with the difference being statistically significant (P-value < 0.01). Full ZR had higher model microstrain values than PEEK & ZR, with the difference being statistically significant (P-value < 0.01), as shown in Table V.

Full ZR separate crowns had higher crown microstrain values than PEEK & ZR, with the difference being statistically significant (P-value < 0.01). Full ZR had higher model microstrain values than PEEK & ZR, with the difference being statistically significant (P-value < 0.01), as shown in Table VI.

DISCUSSION

This study was conducted to investigate the biomechanical behavior of different implant prosthetic designs and restorative materials by measuring the benefits of adding PEEK framework to the prosthetic design and its effect on the restoration and substrate using strain gauge analysis.

Table III - Effect of different designs of implant restorations on specific crown and model micro strain (µm/µm) regardless of material type

	Group FB (Fixed bridge)			Group CB (Cantilever bridge)			Group SC (Separate crowns)			P-value	Post Hoc analysis by LSD		
	Mean	SD	SE	Mean	SD	SE	Mean	SD	SE		P1	P2	P3
5C	26.00	4.59	1.45	84.50	77.04	24.36	34.00	21.83	6.90	0.018	0.009	0.702	0.022
5M	914.50	322.85	102.09	706.50	404.22	127.83	1368.00	571.43	180.70	0.008	0.305	0.031	0.003
6C	25.00	14.34	4.53	109.00	91.25	28.86	36.50	15.10	4.78	0.003	0.002	0.638	0.006
6M	275.50	95.20	30.11	2487.50	1501.03	474.67	1656.50	690.62	218.39	0.000	0.000	0.003	0.062
7C	23.50	6.26	1.98	106.00	101.67	32.15	35.00	13.74	4.35	0.009	0.004	0.668	0.013
7M	906.50	330.75	104.59	2064.00	1257.85	397.77	1352.50	534.66	169.07	0.013	0.004	0.230	0.060

Mean and Standard deviation (SD). •One Way ANOVA test. **P1:** Comparison between **Group FB** and **Group CB**; **P2:** Comparison between **Group FB** and **Group SC**; **P3:** Comparison between **Group CB** and **Group SC.**

Table IV - Effect of material type on crown and model micro strain (µm/µm) in (Fixed bridge) implant restoration design

	Group FB (Fixed bridge)					
	Sub group I (Full ZR)		Sub group II (PEEK&ZR)		Test value•	P-value
	Mean	SD	Mean	SD		
5C	28.00	5.70	24.00	2.24	1.461	0.182
5M	1194.0	188.63	635.00	60.31	6.312	0.000
6C	38.00	4.47	12.00	4.47	9.192	0.000
6M	363.00	16.81	188.00	31.14	11.057	0.000
7C	26.00	6.52	21.00	5.48	1.313	0.226
7M	1202.0	164.23	611.00	29.45	7.921	0.000

Mean and Standard deviation (SD).

Table V - Effect of material type on crown and model microstrain (μm/μm) in (Cantilever bridge) implant restoration design

	Group CB (Cantilever bridge)					
	Sub group I (Full ZR)		Sub group II (PEEK&ZR)		Test value*	P-value
	Mean	SD	Mean	SD		
5C	157.00	14.40	12.00	2.74	22.112	0.000
5M	1081.0	125.27	332.00	36.33	12.841	0.000
6C	195.00	15.00	23.00	4.47	24.571	0.000
6M	3901.0	195.91	1074.00	190.08	23.158	0.000
7C	200.00	33.91	12.00	4.47	12.290	0.000
7M	3243.0	278.92	885.00	83.82	18.104	0.000

Table VI - Effect of material type on crown and model micro strain (μm/μm) in (Separate crowns) implant restoration design

	Group SC (Separate crowns)					
	Sub group I (Full ZR)		Sub group II (PEEK&ZR)		Test value*	P-value
	Mean	SD	Mean	SD		
5C	54.00	7.42	14.00	4.18	10.505	0.000
5M	1846.0	380.17	890.00	137.66	5.287	0.001
6C	49.00	10.84	24.00	2.24	5.051	0.001
6M	2305.0	115.76	1008.00	91.49	19.656	0.000
7C	46.00	10.84	24.00	2.24	4.445	0.002
7M	1835.0	221.64	870.00	109.77	8.724	0.000

Mean and Standard deviation (SD).

A 3D printed model simulating the mandibular bone with Young modulus similar to human bone marrow, validated by previous studies, was fabricated using a 3D printer with continuous digital light projection [29]. A fully guided implant placing guide was 3D printed and was supported with the corresponding guided implant kit metal sleeves to ensure an accurate implant placement procedure.

The present work tested and compared the strains generated from perpendicular occlusal forces. A vertical load of 100 N was applied for a period of 10 seconds using a Universal Testing Machine. Vertical and horizontal forces are the primary interest loads in restorative dental implantology. In this study, the loaded prostheses were limited to vertical forces. Vertical loading forces were applied to the central fossa. These loading conditions aimed to simulate real-life forces that would be acting on the prostheses if in a mouth. The vertical forces are considered to be more favorable because they distribute stress evenly through the complete fixed prosthesis. These forces are transferred to the implant-abutment connection and the fixture [30,31].

It was used monolithic zirconia, and also a combination of PEEK and zirconia for the designs. All designs were fabricated using a CAD/CAM system. Zirconia and PEEK are both materials that are used successfully to restore posterior edentulous areas. A one-year clinical evaluation, conducted by El Sokkary et al. [32], of fracture and marginal integrity of milled bio HPP polyetheretherketone (PEEK) versus zirconia veneered single crowns, concluded that both Zr veneered and Bio HPP (PEEK) crowns revealed successful clinical performance from the clinical performance aspect and patient satisfaction.

PEEK abutment showed reduced plaque affinity and increased patient satisfaction according to a study conducted by El-Shabrawy et al. [33]. The study was performed to evaluate the use of PEEK abutments versus zirconium abutments with lithium disilicate superstructure on the aesthetic acceptance and peri-implant clinical parameters. Zirconium abutments were found to have high surface roughness even after polishing, which caused a remarkable collapse of the soft tissue papilla and resulted in failed aesthetic restoration.

Results showed that the effect of restoration design has a high impact on microstrain in crown and model regardless of the material type. The cantilever design had higher microstrain values than the separate-crowns design. The separate-crowns design had higher microstrain values than the fixed bridge design, regardless of the material. The highest microstrain was found in the middle crown and middle model area in the cantilever design, regardless of the material. The difference was statistically significant and agreed with Rani et al. [16] *in vitro* study. The reported study compared screw-retained splinted versus screw-retained non-splinted implant-supported prostheses. The authors stated that splinted crowns produce less microstrain when compared to separate crowns, indicating that splinting improves force distribution around peri-implant bone which decreases the chance for microfractures and progressive bone resorption.

In the present study, results showed that the effect of material type has high significance on crown and model microstrain (μm/ μm). The full ZR design had higher crown and model microstrain values than the PEEK & ZR design. The difference was statistically significant. These findings were in agreement with the systematic literature review conducted by Yuan et al. [34], that recommended using a shock-absorbing material to reduce the amount of force transmitted to the bone, leading to a reduction in possible implant failure.

When comparing different full ZR implant restoration designs, results showed that the cantilever design had higher crown and model microstrain values followed by The full ZR separate-crowns design then the full ZR fixed bridge design. The difference was statistically significant. When comparing combined ZR & PEEK designs, results showed that the combined PEEK & ZR cantilever design had higher crown and model microstrain values followed by the combined PEEK & ZR separate-crowns design. then the combined PEEK & ZR fixed bridge design. The difference was statistically significant. This is in conflict with the study conducted by Kaleli et al. [35], comparing stress distribution in single implants and peripheral bone with different restorative crown and customized abutment materials. The results showed that although Zirconia customized abutments exhibited higher stress values than PEEK customized abutments, the stress distributions or energy transfer in the implant and peripheral bone were similar in all models. The study stated that ‘changes in restoration and customized abutment material did not affect stress distribution in the implant and peripheral bone.

CONCLUSION

Within the limitations of this study, the following conclusions were drawn:

1- Splinted prosthetic design presented suitable biomechanical behaviour when compared with the other designs evaluated in this study;

2- Zirconia supported by PEEK framework showed promising strain distribution over crown, substrate and implant, regardless of the prosthetic design.

Authors’ Contributions

MAMA: original draft preparation, Investigations, sample preparation, resources and conceptualization of the project idea, writing and editing. AMH: supervision, project administration, methodology, review, editing, data resources and data curation. GAF: supervision, methodology, data review & editing. AKAE: supervision, methodology, data review, editing of the original draft preparation, formal analysis and writting. All authors have read and agreed to the published version of the manuscript.

Conflict of Interest

No conflicts of interest declared concerning the publication of this article.

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Regulatory Statement

This research was approved by the committee of Faculty of Dentistry Ain Shams University Research Ethics (FDASU-REC).

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