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IN-VITRO EVALUATION OF STRAIN INDUCED BY VARIOUS EXTRA CORONAL ATTACHMENT MATERIALS IN REMOVABLE PARTIAL DENTURES RESTORING MANDIBULAR KENNEDY CLASS I FOLLOWING CLINICAL SIMULATION FOR ONE YEAR

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ABSTRACT

Purpose: The objective of this study was to evaluate the strain induced by various extra coronal attachment materials retaining removable partial dentures restoring mandibular Kennedy class I following clinical simulation for one year.

Materials and Methods: Twelve identical models, fabricated by 3D printing, representing Kennedy class I mandibular partially edentulous cases with bilateral first premolars as primary abutments were used. Each model had four removable dies; canines and first premolars bilaterally. On these dies, bilateral splinted crowns were fabricated and grouped according to the extra coronal attachment material used (PEEK/BioHPP, zirconia and metal). Each group included four models, each model was designed having four slots for strain gauges (two on each side). These slots were positioned 1mm distal to the 1st premolar (SG1 and SG3) and at the edentulous ridge (SG2 and SG4) 1 cm away from the first one. Removable partial dentures were fabricated, and a universal testing machine was employed to assess the strain induced under unilateral and bilateral loading conditions. This assessment was conducted both prior to and after clinical simulation for one year. The clinical simulation involved chewing simulator sessions and cycles of insertion and removal for the denture.

Results: PEEK (BioHPP) group exhibited the least strain induced, both prior to and after clinical simulation for one year, under both unilateral and bilateral loading conditions.

Conclusions: PEEK (BioHPP) extra coronal attachment used for retaining removable partial denture provides more favorable stress dissipation in comparison to zirconia and metal attachments.

KEYWORDS: PEEK, zirconia, metal, strain gauges

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INTRODUCTION

The prosthetic rehabilitation of Kennedy class I partially edentulous cases has always been a challenge for prosthodontists [1]. Different approaches have been explored to address the rehabilitation of partially edentulous situations, such as removable partial dentures (RPDs) retained by clasps or attachments, along with dental implant-supported prostheses [2,3]. Frequent clinical difficulties associated with clasp-retained removable partial dentures (RPDs) include issues such as inadequate retention, instability, increased liability to dental caries in addition to esthetic concerns regarding the visibility of metallic clasps[4-7].

While dental implants offer a solution to several problems associated with removable partial dentures (RPDs), their utilization is constrained by factors such as the patient's systemic condition, bone quality, and financial situation [8,9].

Removable partial dentures retained by attachments provide enhanced retention and aesthetic appeal in comparison to those retained by clasps [10,11]. Additionally, they demonstrate a lower susceptibility to fractures, reduced bulk, and lower susceptibility to secondary caries when compared to clasp retained RPDs [12-15]. An attachment, is a mechanical device designed to secure, retain and stabilize a removable prosthesis [16]. The extra coronal resilient attachments comprise two elements: resilient and rigid components that facilitate articulation, rotation, and frictional movements. The stiff male part, referred to as the patrix, is commonly situated on the crown restoration attached to an abutment tooth, while the flexible negative component, or matrix, is typically integrated into the removable prosthesis [17,18]. In distal extension base cases, it is advisable to utilize resilient extra coronal attachments to reduce abutment torque and distribute the load optimally between abutments and the residual edentulous ridge. Utilizing extra coronal resilient attachments has been noted to decrease stresses on the terminal abutment by redistributing a greater amount of load onto the distal residual edentulous ridge [19]. Furthermore, there are several recommendations to splint abutments with full coverage retainers to decrease stresses caused by extra coronal attachments [20-22].

Nickel-chromium has demonstrated favorable outcomes in clinical usage when employed alongside attachments and metal ceramic restorations. This could be attributed to its high modulus of elasticity, adequate hardness, affordability, as well as the convenience it offers in laboratory procedures[23-24]. Conversely, zirconia exhibits markedly superior mechanical properties compared to other prosthetic ceramic materials, on a level with those of metals used in porcelain fused to metal bridges. Zirconia offers high mechanical properties including fracture toughness, flexural strength and hardness as well as good biocompatibility, esthetic quality, low thermal conductivity and chemical inertness [25,26].

Currently, there is a range of zirconia attachments accessible for retaining RPDs. These include extra coronal attachments, ball attachments integrated into a zirconia post for overdentures, and bar attachments. Yet, the existing literature lacks sufficient information concerning the use of zirconia extra-coronal attachments for retaining RPDs [25-27].

Furthermore, polyether ether ketone (PEEK) has been applied for dental applications. Unlike metals commonly used in dentistry, PEEK has modulus of elasticity that closely resembles that of bone. It demonstrates high thermal stability, provides favorable aesthetics, biocompatible as well as its light weight [28-30]. Nevertheless, the fracture resistance of PEEK has proven inadequate, prompting the development of a modified version referred to as BioHPP [30]. BioHPP, short for Bio high-performance polymer, is a modified form of PEEK including ceramic fillers around 20%. Introduced by Bredent GmbH, BioHPP has been specifically designed for dental purposes due to its outstanding properties. The incorporation of distinct ceramic fillers, with particle sizes ranging from 0.3 to 0.5 microns, led to uniform consistency, excellent polishing characteristics, and elevated mechanical strength [30,31].

The rapid and ongoing advancements in computer-aided design as well as computer-aided manufacturing (CAD/CAM) have made the utilization easier for a range of novel materials that can be accurately milled for creating planned dental prostheses. Recently, dental restorations produced through technology of CAD/CAM have gained widespread popularity primarily due to the swift automated manufacturing procedure [32,33].

A comprehensive understanding of the unique characteristics and responses of the tissues supporting distal extension removable partial dentures is essential for their clinical success. These characteristics coupled with functional aspects create major stresses on the tooth-tissue borne RPD. Moreover, the abutment teeth and the supporting structures of the prosthesis undergo stresses not just during regular function but also during the procedures of insertion and removal. If these stresses surpass the normal physiologic limit, it may lead to alveolar bone resorption, abutment loss, and ultimately prosthesis failure [34]. Likewise, distal extension cases encounter stresses during use, leading to bone resorption, diminished support as well as reduced prosthetic stability requiring regular relining or construction of a new RPD [35,36].

Various techniques have been employed to evaluate the stresses generated in abutment teeth, edentulous ridges, and RPDs [37]. One of the frequently used approaches for stress analysis is the application of electrical strain gauges. These gauges can be utilized for measuring strain induced by static or dynamic loading in both in vivo and in vitro settings. They have been widely employed in stress analysis research articles focusing on various designs of prosthodontic appliances [20, 37, 38]. Strain gauges, defined as miniature electric resistors, function by modifying electrical resistance when exposed to strain caused by the stress applied. The recorded electrical signal is transmitted to a data acquisition board, transformed into a digital signal, and then subjected to computer analysis. These gauges have the ability to accurately record object deformation when subjected to stress. [37, 38]. Multiple researches have explored stress analysis concerning extra coronal attachments through the utilization of strain gauges investigating unilateral, bilateral, or both types of stresses [39-42].

Furthermore, to assess dental materials under conditions closely resembling the oral environment, chewing simulators have been utilized to imitate dynamic movements of the mandible, resembling natural chewing function. These simulators include a counteracting force that applies predefined parameters with a specified weight to a specimen. Different patterns of motion can be planned to replicate a range of mandibular movements [43].

Numerous studies have examined how the material and design variations of extra-coronal attachments impact the strain produced and transmitted by removable partial dentures to the abutment teeth and the edentulous ridge. [10-13,24,39,40]. It has been reported that attachment retained RPDs with zirconia and metal resin bonded attachments generate significantly lower strain values compared to those with extra coronal attachments involving full veneer retainers rendering them a more favorable option for distal extension removable partial dentures [24]. Furthermore, the use of polyetheretherketone (PEEK) as a material for partial denture attachment and framework has been found to decrease induced strain around abutment teeth and edentulous residual ridge [40].

Furthermore, numerous research investigations have assessed how the retention of removable partial dentures, secured by extra coronal attachments, is influenced by repeated cycles of insertion and removal, coupled with occlusal loading simulating clinical performance [44-47]. Nevertheless, the existing literature lacks adequate details concerning the consequences of aging simulating clinical service on various extra coronal attachment materials employed as retainers for removable partial dentures in different environmental conditions, particularly regarding the resultant stresses transmitted to the supporting structures. Hence, the objective of the present investigation was to evaluate the strain generated when utilizing three extra coronal attachment materials ; PEEK (BioHPP), zirconia, and metal, across simulated clinical conditions.. This assessment involved the collective influence of dynamic loading in artificial saliva, and the outcomes of simulating one year of clinical performance through cycles of denture insertion and removal.

The null hypothesis of the current study proposed that there would be no variance in the induced strain among the three tested extra coronal attachment materials, before and after clinical simulation whether under unilateral or bilateral loading.

MATERIALS AND METHODS

Sample size analysis

Statistical power analysis was designed to have adequate power by adopting an alpha (α) and beta (β) levels of (0.05) (i.e., power = 95%), and an effect size (f) of (3.75) calculated based on the results of a previous study [24]; the minimum required total sample size (n) was found to be (6) samples; (2 models per group). G*Power version 3.1.9.7.was used for calculation of the sample. Four models (n=4) were performed for each group in the current study to ensure reliable results.

Samples were randomized using simple random sampling procedure. Each model was assigned a number from (1:12) and the models for each group were allocated using random sequences generated using random.org website.

Design of the study and samples' grouping

Twelve models were fabricated revealing class I Kennedy partially edentulous mandibular arch having the first premolar as a primary abutment on both sides. Each model included four removable dies; canine and first premolar on each side. The research plan included 3D-printed experimental models. According to the material used for fabrication of the extra coronal attachments, the models were allocated randomly into three groups. Each group involved four experimental models (n=4). The random assignment was conducted through a simple random sampling procedure. Each model was assigned a number from (1:12) and the models for each group were allocated using random sequences generated using random.org website.

The initial category is the PEEK (BioHPP) group, which included removable partial dentures (RPDs) with PEEK (BioHPP) extra coronal attachments. The second category is the zirconia group, consisting of RPDs with zirconia extra coronal attachments. The third category is the metal group, which featured RPDs with porcelain fused to metal retainers and metallic extra coronal attachments.

The proposed setup included placing two splinted crowns on the canine and first premolar, each featuring bilateral extra coronal attachments. The study employed a major connector; lingual bar and a combined metallic acrylic resin denture base. For each attachment retained removable partial denture, the average of five strain value measurements (um/m) was calculated.

Experimental models' construction:

An educational Kennedy class I model of the mandibular arch was used for construction of the proposed test models where the first premolar served as the terminal abutment on both sides. A desktop scanner (DOF, South Korea) was used to scan the model. During scanning, the model was securely fixed to the plate of the scanner and coated with (Titanium dioxide-free spray) as an occlusion spray to detect any issues throughout the scanning process. The scanning sequence was executed, resulting in the generation of a STL (standard tessellation language) file using software (Exocad Dental CAD, Exocad Inc., Darmstadt, Germany). Subsequently, the virtual model was designed and modified within the software.

Virtual model modification

Modification to the virtual model was performed to include four abutments, situated at the locations corresponding to the canine and first premolar on both sides. Using the software, the abutment teeth were digitally extracted from their original positions on the virtual model, and separate STL files were generated for the prepared dies. Afterward, these STL files were employed to overlay the prepared abutments onto their corresponding sockets in the model that had been scanned earlier.

The choice for the abutment preparation design was made from the software library to guarantee their alignment perpendicular to the occlusal plane, incorporating a shared pathway for both insertion and removal. The configured abutments were designed with deep chamfer finish lines, each measuring 1.5 mm in thickness, to facilitate the fitting of two splinted crowns on both sides; the extra coronal attachments on each side shared a unified path of insertion. A 2 mm layer was removed from the scanned model crest for mucosal simulation. Additionally, a 0.25 mm space was intentionally left between the inner surfaces of the sockets of the canines and first premolars to replicate the space occupied by the periodontal membrane (Figures 1-3).

Within the software, four slots for strain gauges were created, two on each side, to fit the strain gauge rosettes. The initial slot on both sides (Slot 1& 3) were placed 1mm distal to the sockets of the first premolar bilaterally, while the second slot (Slot 2&4) were situated 1 cm distal to the first slot bilaterally. These slots were designed to be parallel, with dimensions of 2 mm mesio-distally, 5.5 mm bucco-lingually, and 5 mm occluso-gingivally. To achieve a standardized position for the strain gauges in the slots, a depression with dimensions 2 mm bucco-lingual, 4 mm occluso-gingival, and 2 mm in depth in the distal wall of the slot was incorporated (Figure 4).

Subsequently, the STL files were exported to the additive manufacturing device. The Form 2 3D printer from Form labs in Somerville, Massachusetts, United States, was employed for printing the experimental models and dies. The printing procedure entailed a step-by-step

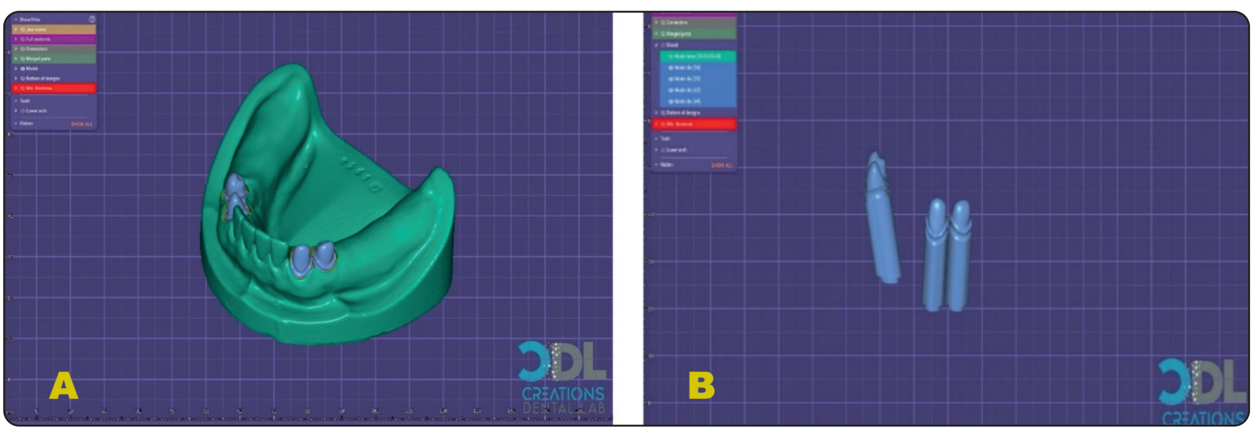

Fig. (1): A: Virtual model. B: Virtually prepared dies.

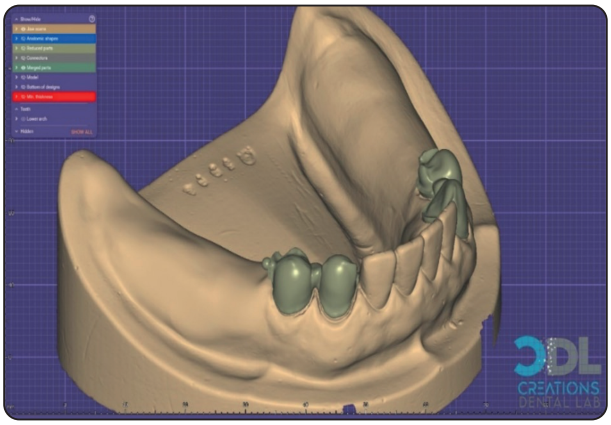

Fig. (2): Scanned model with extra coronal attachments and cut-back for PFM crowns.

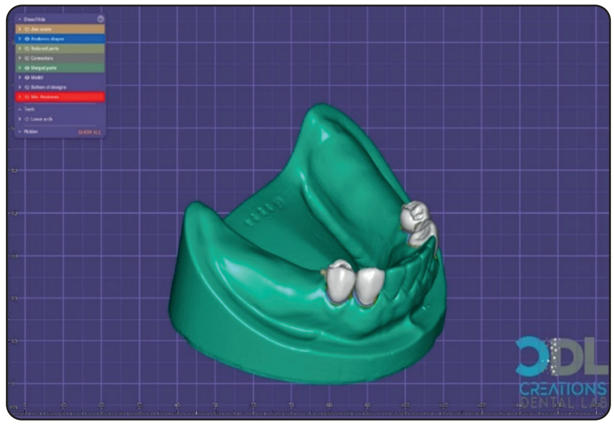

Fig. (3): The designed full anatomical crowns and extra coronal attachments on the virtual model.

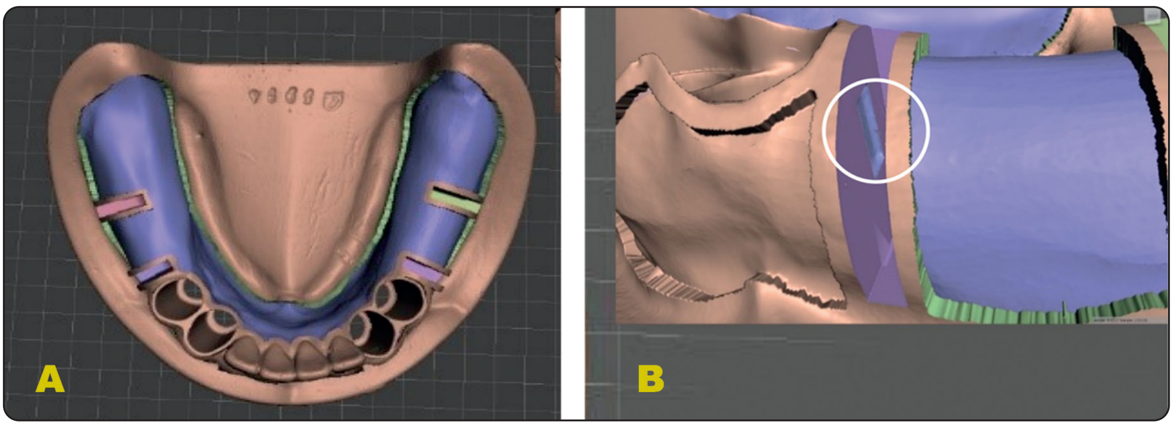

Fig. (4) A: The virtual model displaying strain gauge slots, sockets of prepared abutments and the cut-back for gingival simulation. B: Depression in the distal wall of the strain gauge slot.

implementation, utilizing UV light projection to enable the polymerization of consecutive layers from the bottom to the top, resulting in the successful printing of the entire model and detachable dies (Figure 5). The printing utilized model resin material (Pro shape dental cast resin, Turkey) for both the models and the dies. Two sets of identical individual dies were 3D printed for each prepared model, and their placement within the sockets on both sides of the 3D model was verified.

Gingival simulation

To mimic the gingiva, modeling wax was applied to the 3D model, forming a layer over the designated 2 mm space intended for simulation of the mucosa. This procedure aimed to imitate the viscoelastic characteristics of the muco-periosteum that covers the residual edentulous ridge. Subsequently, light body elastomeric impression material (Affinis, Coltene Whaledent) simulating the soft tissues was administered to the models. The process, guided by the existing teeth, was carried out using a vacuum-formed vinyl transparent stent to precisely reproduce the mucosal structure.

Construction of crowns and extra coronal attachments

Every 3D-printed model, including simulated mucosa and prepared abutments (canine and first premolar on both sides), underwent scanning to

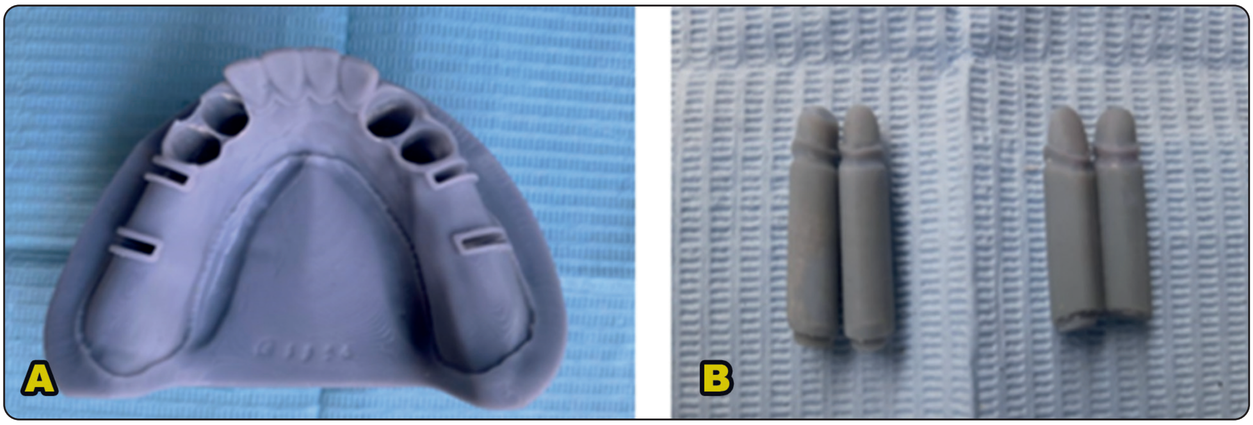

Fig. (5) A: The model after 3D printing showing abutments' sockets, strain gauges' slots and created space for gingival simulation. B: Removable dies after 3D printing.

produce an STL file for the virtual creation of two fully anatomical splinted crowns on the prepared abutments. The bilaterally designed splinted crowns were carefully examined to ensure appropriate dimensions in terms of occluso-gingival, bucco-lingual, and mesio-distal aspects. All surfaces of the crowns were refined to eliminate any sharp or undesirable areas.

Attachments were selected from the library and attached to the distal wall of the first premolar crown on both sides. They were positioned along a line that bisects the angle between the ridge crest and the sagittal plane, leaving an occlusal space of 1mm. The selected extra coronal attachment was an OT-strategy featuring a standard male part of a 1.8 mm sphere (Rhein 83, Bologna, Italy). Following this, the standard tessellation format (STL file) was forwarded to the subtractive manufacturing device (DWX-52D, Ronald DGA, California, USA) to produce the splinted crowns with the intended extra coronal attachment in the following manner:

For the PEEK (BioHPP) group: PEEK (BioHPP) material (blank size 14, Brecam BioHPP, Bredent, Germany) was used for milling the splinted crowns and attachments and then confirmed for an accurate fit with the abutments. The bonding surfaces of the PEEK (BioHPP) retainers were subjected to ultrasonic cleaning in distilled water for a duration of 10 minutes following abrasion with 50 μm Al2O3 airborne particles (at 0.2 MPa and a distance of 10 mm for 10 seconds) [48]. Simultaneously, the dies' bonding surfaces were cleansed using alcohol. Adhering to the manufacturer's guidelines, a primer (Visio.link, Bredent, Germany) was administered, and resin cement. (Panavia V5, Kuraray Noritake Dental Inc., Japan) was used to cement the retainers to the models (Figure 6).

Zirconia group: Zirconia material (Zolid Ceramill Amann Girrbach, GmBH, Germany) was used for milling the splinted crowns and extra coronal attachments via the milling equipment (Shera eco-mill 5x, Werkstoff-Technologie GmbH & Co. KG,

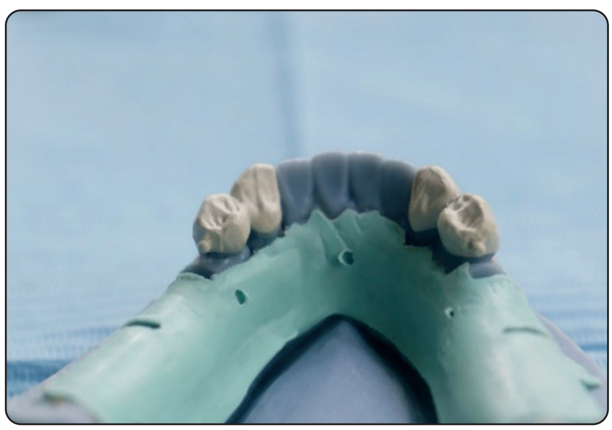

Fig. (6): PEEK (BioHPP) crowns with extra coronal attachments.

Germany). The zirconia crowns were subjected to the sintering process using a conventional sintering system in a furnace (TABEO-1/M/ZIRKON-100, Mihm-Vogt, Germany). All sintering conditions were applied based on the guidelines provided by the manufacturer, including a sintering temperature of 1650ºC and a total process time of 239 minutes, commencing from room temperature. Subsequent to the completion of the sintering process, the crowns and attachments were finished, polished and glazed. Afterward, the zirconia crowns were carefully inspected to ensure precise fitting to the abutments. Surface treatment was applied, and they were cemented using resin cement. The identical process as employed for PEEK (BioHPP) was replicated, with the exception of the primer used. Panavia V5 Tooth Prime (Kuraray Noritake Dental Inc., Tokyo, Japan) was applied based on the guidelines provided by the manufacturer (Figure 7).

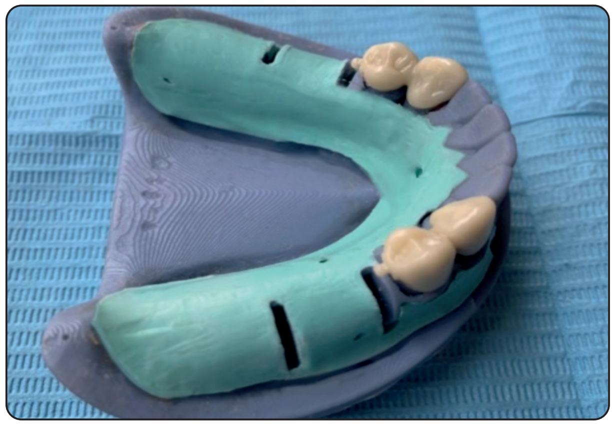

Fig. (7) Zirconia crowns and extra coronal attachments.

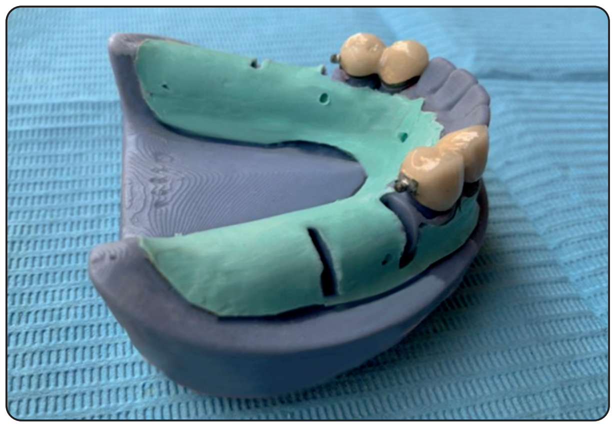

Fig. (8) PFM crowns with the metallic extra coronal attachments.

For the metal group: 3D printing by dental wax (Yamahachi MFG,Co, Japan) was performed for fabrication of the patterns for porcelain-fused-to-metal (PFM) structures, incorporating the extra coronal attachments . Afterward, the wax patterns were subjected to traditional investing and casting in nickel-chromium (Magnum ceramic co, Italy). Following the casting process, the resulting metal structures were subjected to sandblasting, finishing, and polishing, with the exception of the male portion of the attachment. To ensure proper fit with the abutment dies, the metal crowns were then examined, after which porcelain (VITA VMK Master Germany) was fired onto the metallic crowns. The surfaces were treated, and resin cement was used to cement the crowns in position, as previously mentioned for the group of zirconia crowns (Figure 8).

Designing and fabrication of removable partial dentures

The framework for the removable partial denture (RPD) was created using the CAD/CAM design software's partial denture module. The STL files obtained from the virtual models, which included the primary frameworks, were utilized as the foundation for designing customized RPDs for the prepared models, ensuring uniform thickness and design. Each RPD was configured with a unified denture base and a lingual bar major connector. The RPD frameworks' resin patterns were subsequently produced through 3D printing employing castable resin (NextDent B.V., Netherlands). Afterward, these resin patterns underwent the conventional process of investment and casting into cobalt-chromium (Wironium, BegoGmBH, Germany).

The frameworks were meticulously positioned to guarantee an accurate fit on the corresponding models. Following that, an initial wax-up of the removable partial denture (RPD) framework was carried out on each model. Afterward, acrylic resin artificial teeth (Acrostone, Egypt) were added. For standardization of both the thickness of the denture base and the positioning of the artificial teeth in the RPDs, a rubber index mold (Dental Products, 3M Center Building, St. Paul, USA) was created based on the waxed-up RPD. Then, flasking and processing for the waxed-up RPDs were performed using heat-cured acrylic resin (Acrostone, Egypt) to generate uniform RPDs. The attachment housings were incorporated into RPDs' fitting surfaces using self-cure acrylic resin. (Acrostone, Egypt) (Figure 9).

Testing procedures

Installation of strain gauges and analysis of strain

The strain gauges employed in this investigation were provided with a fully encapsulated grid and connected wires (Kyowa Electronic Instruments Co., LTD, Tokyo, Japan). These gauges had a length of 1 mm, a resistance of 119.6 ± 0.4 Ω, and a gauge factor of 2.13% ± 1.0. The strain gauges were attached to the designated locations on the experimental model, aligned with the abutments' longitudinal axes , utilizing a fast-set cyanoacrylate adhesive (Pattex super glue, Henkel, Germany).

Strain gauge measurements were done by a single trained blinded operator for standardization. A 4-channel strain meter (PCD-300 A, Kyowa Electronic Instruments Co.) was used in the current study and calibrated before each measurement session.

After connecting the strain gauges to the strain meter, the model was positioned on the lower plate of the universal testing machine, using a load applicator fixed to the upper section of the universal testing machine (Lloyd LRX; Lloyd Instruments Ltd., Fareham, UK) a static load was exerted with a crosshead speed set at 0.5 mm/min. This process continued until a load of 100 N was reached, at this point the resulting strain was computed.

The load application was conducted unilaterally and bilaterally. A rod-shaped metal load applicator was utilized for unilateral loading. The central occlusal fossa of the left first molar was selected as the point of load application (Figure 10).

In the case of bilateral load application, a rectangular-shaped metal bar having a small depression at its center was positioned on the occlusal surface of the artificial teeth in the first molar region bilaterally. Application of load was

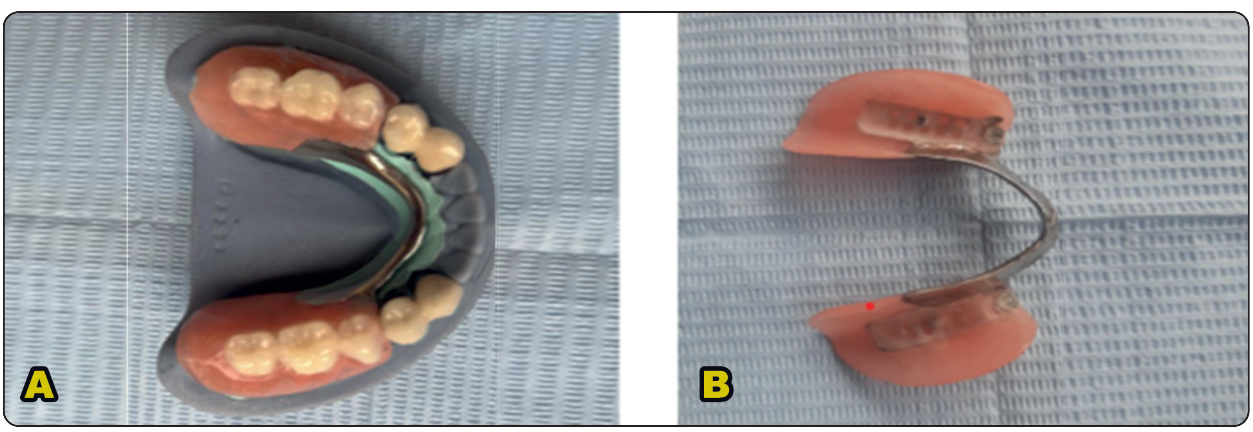

Fig. (9): A: The removable partial denture (RPD) retained by extra coronal attachments. B: The nylon OT caps in the fitting surface of the RPD.

Fig. (10) Load application unilaterally on the RPD using the universal testing machine.

performed by means of the load applicator secured to the upper compartment of the universal testing machine. The point of load application was the center of the metal bar (Figure 11).

For each reading, five measurements were taken with a minimum of 15 minutes between each two measurements. The recorded strain values were averaged, and the mean values were collected, tabulated, and subjected to statistical analysis.

Aging procedures

The strain gauges were dislodged from their designated slots before initiating the aging procedures. To replicate the oral environment, a chewing simulator (CS-4.4; SD Mechatronic, Germany) was employed. The mounting ring of the chewing simulator was coated with Vaseline. Each model was positioned so that the load applicator was aligned with the small depression marked at the center of the metal bar on the occlusal surface of the artificial teeth in the first molar region bilaterally. This setup aimed to simulate the typical load experienced in the posterior region of the oral cavity. Then the model was firmly anchored in place utilizing cold cure acrylic resin. The chewing simulator parameters were configured with the following settings: 60 mm/s speed, 3 mm vertical path, 0.7 mm horizontal path, 1.6 Hz frequency, and 50 N force [49].

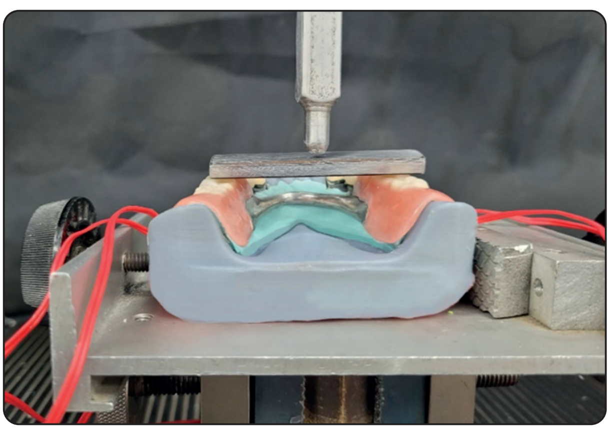

Fig. (11) Load application bilaterally on the RPD using the universal testing machine.

Based on Glandosane® (Fresenius Kabi Ltd, Germany) formula [49,50], artificial saliva was formulated in the lab of pharmaceutical industry at the Faculty of Pharmacy, Ain-Shams University, and used to fill the compartments of the chewing simulator.

Each model was subjected to vertical cyclic loading, comprising 240,000 cycles, representing one year of clinical performance [49-51] (Figure 12).

Assuming that the denture is typically inserted and removed by the patient approximately four times daily (after each meal and prior to bedtime), an overall of 1,440 cycles of insertion and removal were implemented for each RPD, representing the clinical performance for one year [51-53]. This was

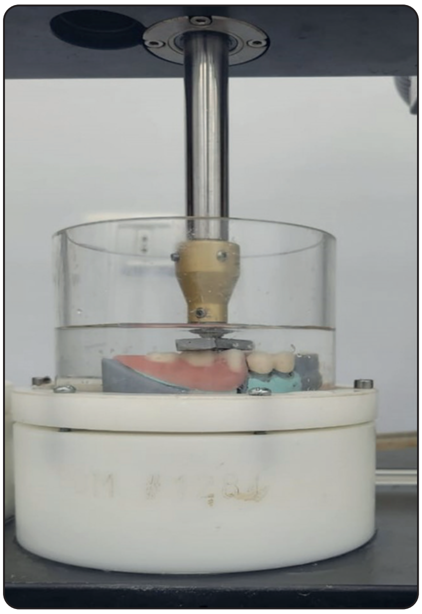

Fig. (12) Application of load on the RPD in the chewing simulator.

followed by installation of new strain gauges in the same position of the original ones guided by the depressions created in the strain gauge slots. The new strain gauges were then connected to the strain meter. In order to assess the strain induced at the abutments and the residual edentulous ridge, load was applied as previously mentioned by the universal testing machine after repositioning each model with its respective RPD.

Statistical analysis

Statistical analysis was performed using SPSS statistical package for social sciences, version 22 (SPSS Inc., Chicago, IL). Data were tested for normality using Kolmogorov-Smirnov and Shapiro-Wilk tests where the analyzed data revealed normal distribution. The influence of the material of extra coronal attachment in addition to the effect of clinical simulation for one-year period on the resulting strain was statistically analyzed using repeated measures ANOVA followed by Tukey's post hoc test for pairwise multiple comparisons with a significance $p < 0.05$.

RESULTS

Statistical analysis showed that the material of the extra coronal attachment and the influence of clinical simulation for one year as well as their interaction had a significant effect on the resulting strain ($P > 0.0001$). The strain resulting from unilateral loading prior to and after clinical simulation for one year showed substantially lower values recorded for PEEK (BioHPP) group distal to the abutments (SG1 & SG3) for the loaded as well as the unloaded sides compared to zirconia and metal groups which showed insignificant difference between each other.

Nevertheless, Zirconia group recorded the highest significant strain values on the edentulous ridge (SG2 & SG4) after clinical simulation for one year, while PEEK (BioHPP) group revealed the lowest mean strain values .The statistical analysis revealed no significant variances among the mean strain values registered prior to and after clinical simulation for one year for both PEEK (BioHPP) and metal groups. Comparing the induced strain within each group revealed the lowest mean value at SG3 followed by SG4, SG1 then SG2 which showed the highest value with significant differences observed at the different SG channels (Table 1 & Figure 13).

For bilateral loading, statistical analysis revealed that PEEK (BioHPP) group registered the lowest mean strain values prior to and following clinical simulation for one year, with no statistically significant difference in the resulting strain. A statistically significant reduction in the induced strain was recorded distal to the abutments (SG1& SG3) for zirconia group following clinical simulation for one year conversely, a significantly higher strain was observed at the residual edentulous ridge (SG2 & SG4). The group of metal attachments demonstrated no significant variances prior to and following one year of clinical simulation. Comparing the induced strain among each group showed statistically lower strain values at SG1 & SG3 than those recorded at SG2 & SG4. (Table 2 & Figure 14).

TABLE (1) Mean, standard deviation values and significance of the induced strain (um/m) distal to the abutments and the distal edentulous ridge for the investigated extra coronal attachment materials under unilateral loading both prior to and following clinical simulation for one year.

Attachment material	**Initial unilateral strain induced by the investigated attachment materials**			**The unilateral strain induced by the investigated attachment materials following clinical simulation for one year**			**P value**
Strain gauge channel	**PEEK (Bio HPP)**	**Zirconia**	**Metal**	**PEEK (Bio HPP)**	**Zirconia**	**Metal**	
SG1 (Loaded side)	181.9 ± 14.31 Bb	396.13 ± 28.41 Ab	355.8 ± 23.7 Ab	186.7 ± 13.85Bb	356.34 ± 27.51Ab	342.33 ± 24.6Ab	P<0.0001*
SG2 (Loaded side)	317.8 ± 18.92 Ca	469.9 ± 38.24 Ba	431.54 ± 15.46 Ba	324.85 ±16.94Ca	522.43 ± 35.12Aa	464.27 ± 18.92Ba	P<0.0001*
SG3 (unloaded side)	85.82 ± 6.23 Bd	175.54 ± 13.82 Ad	170.85 ± 15.32Ad	80.11 ± 6.7 Bd	199.14 ± 17.92Ad	174.72 ± 15.17Ad	P<0.0001*
SG4 (unloaded side)	136.85 ± 14.57 Cc	224.21 ± 14.89 Bc	211.12 ± 16.82Bc	140.93 ± 13.65Cc	265.15 ± 17.66Ac	224.83 ± 15.76 Bc	P<0.0001*
P value	P<0.0001	P<0.0001	P<0.0001	P<0.0001	P<0.0001	P<0.0001	

Means with different upper-case superscript letters denote significant differences among rows while those with different lowercase superscript letters indicate significant differences among columns, * indicates significance at P<0.05.

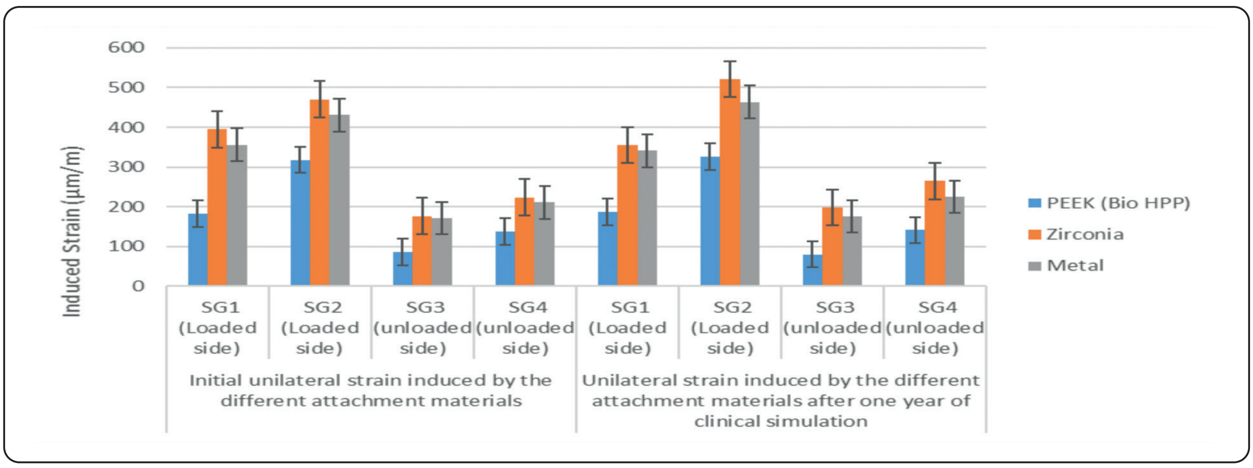

Fig. (13): Bar chart illustrating the induced strain (um/m) distal to the abutments (SG1 & SG3) and the distal edentulous ridge (SG2 & SG4) for the investigated extra coronal attachment materials under unilateral loading both prior to and following clinical simulation for one year.

TABLE (2) Means, standard deviation values and significance of the induced strain (um/m) at the abutment and the distal edentulous ridge for the investigated extra coronal attachment materials during bilateral loading before and after clinical simulation for one year.

Attachment material	Initial bilateral strain induced by the investigated attachment materials			Bilateral strain induced by the investigated attachment materials following clinical simulation for one year			P value
Strain gauge channel	PEEK (Bio HPP)	Zirconia	Metal	PEEK (Bio HPP)	Zirconia	Metal	
SG1	112.3 ± 10.2 C b	258.25 ±24.61Ab	243.98± 26.21Ab	104.91 ± 6.11Cb	182.22 ± 19 .67 Bb	217.81 ±14.48 Ab	P<0.0001*
SG2	234.96± 18.71 Ca	351.9 ± 17.62 Ba	334.4 ± 32.24Ba	269.9 ±15.13Ca	411.35 ±32.47Aa	361 .98 ±19.59Ba	P<0.0001*
SG3	107.98 ± 9.57 Cb	251.31 ± 12.56Ab	239.16 ± 15.65Ab	112.23 ±7.23Cb	177.18 ±10.79Bb	227.97 ±18.72Ab	P<0.0001*
SG4	227.14 ± 19.6 Ca	349.12 ± 30.34Ba	339.92 ± 28.22Ba	263.92 ±17.34Ca	431.28 ± 24.68Aa	370.18 ±19.87Ba	P<0.0001*
P value	P<0.0001	P<0.0001	P<0.0001	P<0.0001	P<0.0001	P<0.0001	

Means with different upper-case superscript letters denote significant differences among rows while those with different lowercase superscript letters indicate significant differences among columns, * indicates significance at P<0.05.

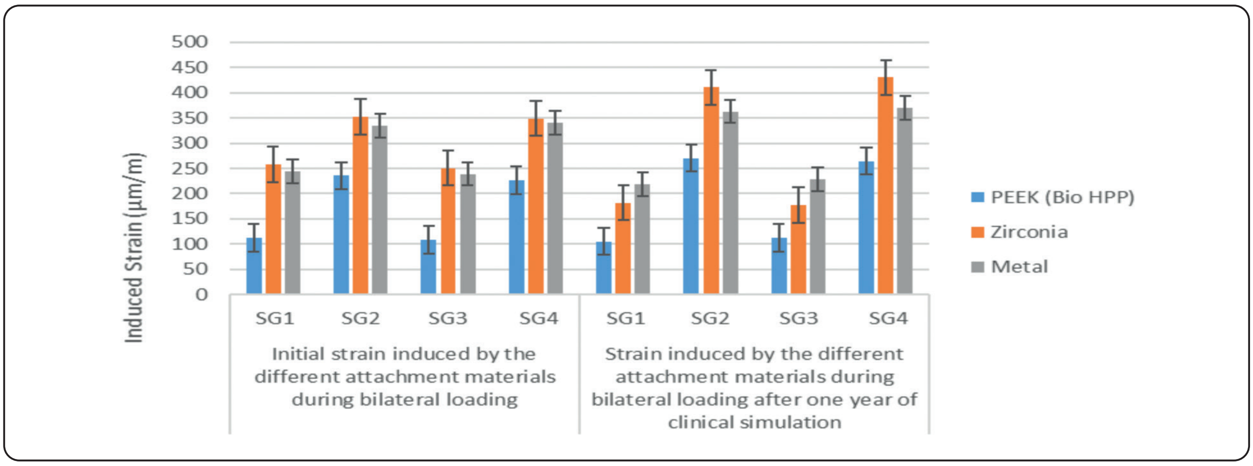

Fig. 14: Bar chart illustrating the induced strain (um/m) distal to the abutments (SG1 & SG3) and the distal edentulous ridge (SG2 & SG4) for the investigated extra coronal attachment materials under bilateral loading, both prior to and following clinical simulation for one year.

DISCUSSION

Attachments utilized as RPD retainers represent a significant treatment modality, offering advantages in terms of enhancing the esthetic outcomes [20,23]. Additionally, they contribute to a more favorable distribution of stress on natural teeth and provide protection for the periodontal structures, compared to clasp retained RPDs [34,54]. The current research specifically focused on mandibular class I Kennedy RPDs, incorporating two splinted crowns on the canine and first premolar bilaterally. This design choice aligns with recommendations emphasizing the involvement of a minimum of two abutments in free end edentulous cases to minimize stresses transmitted to the abutment teeth [20,55].

For the extra coronal attachment system in this study, the RHEIN 83 OT CAP attachment system was employed attributed to its popularity and simplicity in clinical design. It is recommended for cases with limited inter-arch space. The male component of this attachment system features a sphere with a flat head, strategically placed on the distal aspect of the splinted crowns to ensure optimal vertical space for enhanced aesthetics. The corresponding female component incorporates retentive nylon caps, color-coded to indicate varying retentive properties. The utilization of such nylon caps, imparts resiliency and facilitates stress-breaking effect [55-57].

Digital printing of three-dimensional models was employed to ensure uniformity across the test groups. This approach is not only time saving compared to conventional techniques but also enhances accuracy while minimizing manufacturing errors [24,58]. The advantages of digital design include the ability to standardize the position of slots for strain gauges in relation to the abutment teeth, surpassing the accuracy of manual placement. This leads to a uniformly smooth surface, thereby decreasing the chances of recording strain caused by rough surfaces.

In order to replicate the viscoelasticity of the mucoperiosteum that covers the residual edentulous ridge, mucosal simulation was incorporated with thickness of 2 mm approximately. The use of addition silicone elastomeric impression material was chosen for its high dimensional stability, negligible permanent deformation, and a shorter elastic recovery duration compared to other materials [38,48].

A lingual bracing arm was not applied in the partial denture design of the current study as it has been reported that reciprocation in attachment retained RPD does not necessitate the use of a lingual bracing arm, as cross arch stabilization is achieved through splinting of the abutment teeth as well as the use of a rigid major connector [59].

Preservation of the normal contour in the lingual surface of the artificial crown and elimination of the modification for the bracing arm has shown to enhance patients' comfort, reduces food stagnation and plaque accumulation if compared to a lingual bracing arm [60]. Moreover, Saito et al, concluded in their study that an attachment retained RPD denture with an added lingual bracing arm resulted in greater stress on the supporting teeth compared to a denture without such an arm. From a mechanical standpoint, the bracing arm takes up a significant portion of the occluso-gingival height of the abutment tooth, positioning itself closer to the abutment tooth center of rotation. Consequently, the forces generated by the RPD align with the long axis of the tooth, making this configuration ideal for conventional clasp retained RPDs [61]. Nevertheless, it has been reported that the attachment retainer resulted in less strain on the abutment tooth compared to the conventional clasp. This was attributed to the placement of the retentive clasp arm on the facial surface of the tooth, whereas an attachment retainer is positioned on the axial proximal surface. Consequently, all stresses are directed along the long axis of the tooth and are resisted by almost all the fibers of the periodontal ligament. This directed stress closer to the center of rotation of the tooth, making it more advantageous in terms of leverage compared to a conventional clasp. [62].

Strain gauges are widely employed for assessing induced strain in various dental fields due to high precision, compact size, and minimal interference during testing procedures [38,48]. The force utilized for strain measurement with strain gauges was around 100 N, aligning with the normal biting force needed for different types of food. A 15-minute interval was maintained between each pair of measurements to allow the resilient structures to fully rebound [48].

The point for applying the load was designated at the central fossa on the occlusal surface of the first molar during unilateral loading because it signifies the occlusion center [41]. In the case of bilateral loading, both in the universal testing machine and the chewing simulator, a rectangular-shaped bar of metal was positioned on the occlusal surface of the artificial teeth in the first molar region bilaterally. A diamond bur was used to mark the center of rectangular metal bar for standardization of load application position and prevention of unintentional movement of the tip of the load applicator while conducting the experimental measurements, thus ensuring the reliability of the results [24].

When evaluating the stresses induced and resultant strain in dental prostheses, it is essential to consider their ongoing exposure to different environmental conditions in the oral cavity, including humidity and the mechanical forces associated with chewing. Additionally, the frequent placement and removal of prosthesis may impact the stress distribution pattern, potentially leading to alterations in the materials employed in extra coronal attachment-retained RPDs. Simulating these conditions in a controlled laboratory setting becomes crucial for thoroughly assessing the mechanical performance and durability of various prosthetic devices [43-45].

Therefore, the research was formulated to evaluate the strain generated under dynamic loading conditions using a chewing simulator and within an artificial saliva environment serving as an aqueous medium. Furthermore, the study considered the impact of insertion and removal cycles, mimicking a one-year clinical performance for the denture.

Since waterproof strain gauges were not commercially available, the strain gauges were removed before chewing simulation and replaced later by new ones, being installed in the same position of the original ones guided by the depressions created in the strain gauge slots. The aim of such a procedure was to guard against the possible effect of humidity on the strain gauges during chewing simulation being prone to swelling and corrosion of the gauges as well as alteration of their electrical properties due to the presence of the artificial saliva that could have resulted in changes in their resistance and capacitance.

Statistical analysis revealed a notable discrepancy in the strain caused by the three examined materials for extra-coronal attachments, with PEEK (BioHPP) exhibiting the least amount of strain induced in comparison to both metal and zirconia groups during loading both unilaterally and bilaterally. This observation could be clarified by considering the modulus of elasticity for BioHPP (3-4 GPa) [63] in contrast to the significantly higher moduli of zirconia with value higher than 200 GPa [64] and nickel-chromium approximately 190 GPa [65]. The elevated moduli of zirconia and nickel-chromium, in comparison to the modulus of cortical bone in humans nearly 14 GPa [63] could contribute to the increased induced strain observed.

The close correspondence between the modulus of elasticity for BioHPP and human bone contributes to superior distribution of stress. Additionally, the resilient nature of BioHPP serves as a shock-absorbing mechanism, acting as a cushion that decreases the stresses transmitted to the supporting abutment teeth and residual edentulous ridge [66-68].

Furthermore, the minimal difference in the values of modulus of elasticity between zirconia and metal could account for the lack of significant difference in the strain induced among both groups prior to and after one year of simulated clinical performance when loaded unilaterally and bilaterally. This finding aligns with the observations of Nassouhy and Abdalla [23], who, conducted a clinical study, reporting comparable clinical and radiographic outcomes between zirconia and metallic attachments in free end cases over a follow-up period of one year. Similarly, these results are consistent with those reported by ElAswad and Youssef [24].

Before the initiation of clinical simulation, statistical analysis demonstrated markedly higher strain values recorded at the residual edentulous ridge (SG2 & SG4) when subjected to bilateral loading as well as the loaded side when the load was applied unilaterally in comparison to those recorded at the distal aspect of the abutments (SG1 & SG3) for all investigated groups. This finding could be explained based on the variation in the compressibility between the abutment teeth and the viscoelastic soft tissues covering the edentulous ridge leading to rotational displacement of the RPD under the application of load.

Despite the inherent complexity in stress distribution within bilateral free-end saddle cases, the microstrain recorded distal to the abutment teeth predominantly exhibited compressive characteristics. In contrast, the microstrain recorded on the residual ridge was predominantly tensile in nature, aligning with findings reported by Elsyad et al [41]. The abutments are anticipated to experience compressive stresses as the occlusal load is transmitted through them to the underlying bone. However, the edentulous ridge is likely to be subjected to tensile stresses as the occlusal load tends to pull the denture away from the ridge. Additionally, the ball attachment situated near the edentulous ridge may produce a leverage action leading to greater stress concentration, thereby intensifying the strain induced on the residual edentulous ridge. This observation is consistent with the findings reported by ElAswad and Youssef [24] as well as Elsyad et al [41].

Following clinical simulation for one year, the stress distribution exhibited a consistent outline among the removable partial dentures using the three investigated materials for fabrication of extra coronal attachments, with the exception of the group of zirconia attachments , which demonstrated the most notable statistically significant increase in strain values at SG2 and SG4 (at the residual edentulous ridge) under loading conditions both unilaterally and bilaterally. Nevertheless, under bilateral loading conditions, the zirconia group demonstrated significantly reduced induced strain in comparison to the metal group at both SG1 and SG3 (located distally to the abutments). On the other hand, the group of PEEK (BioHPP) attachments continued to display the minimal strain levels in comparison to the other attachment materials following clinical simulation for one year.

The significant rise in the load transmitted to the residual edentulous ridge with zirconia group after 240,000 cycles in artificial saliva within the chewing simulator coupled with the impact of 1,440 cycles of insertion and removal of the RPDs, may be credited to the anticipated nylon cap wear. This wear might result from the substantial hardness difference between zirconia and the nylon cap, possibly resulting in retention loss. Consequently, this alteration in the stress distribution pattern allows partial dissipation of induced stresses distal to the abutments under bilateral loading, leading to increased transmission of stresses to the residual edentulous ridge [69-72]. This rationale is consistent with the recommendation of the attachment manufacturer for annual replacement of the nylon cap.

According to the findings of the present investigation, the initially proposed null hypothesis was rejected, as the statistical analysis indicated statistically significant differences among the tested extra coronal attachment materials prior to and following clinical simulation for one year under both loading patterns. While acknowledging the limitations of this study, it is worthy to note that evaluating more extended periods, various types of extra coronal attachments as well as alternative designs for RPDs remains necessary. Additionally, it is crucial to approach the reported results from a biomechanical standpoint, recognizing that the models utilized in the study represent a simplified version of the assessed structures without accounting for patient-related factors.

CONCLUSIONS

Considering the constraints inherent in the current study, it could be deduced that PEEK (BioHPP) demonstrates superior effectiveness in dissipation of the induced stresses when employed as RPD extra coronal attachment in comparison to both metal and zirconia. Furthermore, following clinical simulation for one year, it is apparent that zirconia has a more detrimental impact on the stresses transmitted to the residual edentulous ridge in contrast to PEEK (BioHPP) however, the metallic extra coronal attachment maintained a consistent pattern.

REFERENCES

1. Carr AB, Brown DT. McCracken's removable partial prosthodontics. 2015. P 21-8. 13 ed. Elsevier Health Sciences.

2. Gonçalves TM, Campos CH, Rodrigues Garcia RC: Mastication and jaw motion of partially edentulous patients are affected by different implant-based prostheses. J. Oral Rehabil.2014; 41:507-14.

3. Swelem AA, Gurevich KG, Fabrikant EG, et al: Oral health–related quality of life in partially edentulous patients treated with removable, fixed, fixed-removable, and implant-supported prostheses. Int. J. Prosthodont. 2014; 27:338-47.

4. Gonçalves TM, Campos CH, Garcia RC. Implant retention and support for distal extension partial removable dental prostheses: Satisfaction outcomes. J. Prosthet. Dent. 2014; 112:334-9.

5. Zancopé K, Abrão GM, Karam FK, Neves FD. Placement of a distal implant to convert a mandibular removable Kennedy class I to an implant-supported partial removable Class III dental prosthesis: A systematic review. J. Prosthet. Dent. 2015; 113:528–33.e3.

6. Kono K, Kurihara D, Suzuki Y, Ohkubo C. Pressure distribution of implant-supported removable partial dentures with stress-breaking attachments. J. Prosthodont. Res. 2014; 58:115–20.

7. Wagner B, Kern M. Clinical evaluation of removable partial dentures 10 years after insertion: success rates, hygienic problems, and technical failures. Clin.Oral Investig. 2000; 4: 74–80.

8. Turkyilmaz I. Use of distal implants to support and increase retention of a removable partial denture: a case report. J. Can. Dent. Assoc. 2009; 75: 655–8.

9. Burns DR, Ward JE. Review of attachments for removable partial denture design: 1. Classification and selection. Int. J. Prosthodont. 1990; 3:98-102.

10. Chander GN. Palliative Care with Attachment Hybrid Removable Prosthesis. J. Clin. Diagn. Res. 2017;11: ZD45–ZD46.

11. Kanathila H, Doddamani MH, Pangi A. An insight into various attachments used in prosthodontics: A review. Int. J. Appl. Dent. Sci. 2018; 4:157–60.

12. Patil R, Shetty O. Prosthetic rehabilitation using extra coronal attachments. J. Clin. Diagn. Res. 2019;4:5–8.

13. Swelem AA, Abdelnabi MH. Attachment-retained removable prostheses: Patient satisfaction and quality of life assessment. J. Prosthet. Dent. 2021; 125:636–44.

14. Gupta A, Khanna G, Bhatnagar M, Markose GM, Singh S. Precision Attachments in Prosthodontics: A Review. Int. J. of Clin. Prev. Dent. 2018;5:34–9.

15. Saneja R, Bhatnagar A, Raj N, Dubey P. Semi precision attachment: A connecting link between the removable and fixed prosthesis. BMJ Case Rep. 2020; 13:1-5

16. Glossary of Prosthodontic Terms, Ninth Edition; J. Prosthet. Dent. 2017 May ;117: e1-e105.

17. Becerra G, Mac Entee M. A classification of precision attachments. J. Prosthet. Dent. 1987; 58:322-7.

18. Jenkins G, Gidden J. Treatment planning. In: Precision attachments: a link to successful restorative treatment. 1999. p. 11. London: Quintessence.

19. Hakim M, Badr A. Evaluation of Biting Force for Three Different Partial Denture Modalities in Bilateral Distal Extension Cases (Crossover Study). Egypt. Dent. J. 2020; 66:1155–62.

20. El Charkawi HG, elWakad MT. Effect of splinting on load distribution of extracoronal attachment with distal extension prosthesis in vitro. J. Prosthet. Dent. 1996; 76:315-20.

21. Orujov K, Winter W, Karl M, Heckmann S, Grobecker-Karl T. Adhesive removable partial denture attachments made from zirconia ceramic: A finite element analysis and in vitro study. J. Prosthet. Dent. 2022; 127:302-7.

22. Schmitt J, Wichmann M, Eitner S, Hamel J, Holst S. Five-year clinical follow-up of prefabricated precision attachments: a comparison of uni- and bilateral removable dental prostheses. Quintessence Int.2011; 42:413–8

23. Nagla Nassouhy and Mohamed Farouk Abdalla. Zirconia versus metal CAD/CAM extracoronal attachments for the bilateral distal extension removable partial denture. Egypt. Dent. J. 2017; 63: 2629-37.

24. Rehab H. Alaswad and Hana'a G. Youssef. Strains induced by zirconia and metal resin bonded attachments versus extracoronal attachment with full veneer retainer in maxillary distal extension removable partial dentures. Egypt. Dent. J.2022; 68: 3809-22.

25. Basutkar N, Aljohani A, et al. Application of CAD–CAM Milled Zirconia Attachment in Kennedy's Class III Partially Dentate Situation: A Series of Clinical Reports. Int.j.prosthodont. restor. dent.2019;9:63–6.

26. Ostrc T, Berce B, Rener-Sitar K. A Combination of CAD/CAM-Fabricated Zirconia Milled Bars and a Gold-Electroplated Superstructure Framework for an Implant- Supported Overdenture: A Case Report. Int. J. Prosthodont. 2020; 33:572-5.

27. Altonbary GY, Emera RMK. Patient satisfaction and masticatory performance of zirconia bar compared to cobalt chromium bar retaining mandibular implant overdenture: A crossover study. J. Oral Rehabil.2021;48:827-35.

28. Veena B Benakatti,+ Jayashree A Sajjanar , Aditya Acharya: Polyetheretherketone (PEEK) in Dentistry. J. Clin. Diagn. Res. 2019 Aug, Vol-13: ZE10-ZE12.

29. Chen X, Mao B, Zhu Z, Yu J, Lu Y, Zhang Q, et al. A three-dimensional finite element analysis of mechanical function for 4 removable partial denture designs with 3 framework materials: CoCr, Ti-6Al-4V alloy and PEEK. Sci. Rep. 2019; 9:1–10.

30. Skirbutis G, Dzingute A, Masiliunate V, Sulcaite G, Zilinskas j. A review of PEEK polymer's properties and its use in prosthodontics. Stomatologija. 2017; 19:19-23.

31. Vijaya Kumar Rajamani, Sandeep Singh Reyal, Eraiah Mahesh Gowda, Muttige Parameshwara Shashidhar. Comparative prospective clinical evaluation of computer aided design/ computer aided manufacturing milled BioHPP PEEK inlays and Zirconia inlays. J.Indian Prosthodont. Soc. 2021;21: 240-8.

32. Miyazaki T., Hotta Y., Kunii J., KuriyamaS. and Tamaki Y.: A review of dental CAD/CAM: current status and future perspectives from 20 years of experience. Dent. Mater. J. 2009; 28:44-56.

33. Brenes C., DuqumI. and Mendonza G.: Materials and systems for all ceramic CAD/CAM restorations. Dental Tribune. CAD/CAM International Magazine of Digital Dentistry. 2016; 3:10-5.

34. Rodrigues RC, Faria AC, Macedo AP, de Mattos Mda G, Ribeiro RF. Retention and stress distribution in distal extension removable partial dentures with and without implant association. J. Prosthodont. Res. 2013; 57:24-9.

35. Jones J D. Turkyilmaz JI, and Garcia LT. Removable partial dentures–treatment now and for the future. Tex. Dent. J. 2010; 127: 365-72.

36. Pesqueira AA, Goiato MC, Filho HG. Use of stress analysis methods to evaluate the biomechanics of oral rehabilitation with implants, J. Oral Implantol.2014; 40:217–28.

37. Sherif Fayez Ahmed Bahgat and Mahmoud El Moutassim Bellah El Homossany. Effect of material on stress transmission to the supporting structures in Kennedy class I restored by telescopic-retained removable partial denture (Strain gauge study). Egypt. Dent. J.2018; 64: 559-73.

38. Heba E. Khorshid. A comparison between two types of attachments in implant retained mandibular over dentures (A stress analysis study). Egypt. Dent. J.2018;64: 1893-902.

39. Saleh MM, Aldori D. Effects of New Modification in the Design of the Attachments Retaining Distal Extension Partial Denture on Stress Distribution Around the Abutments And Residual Ridges: An In Vitro Study. Dent. Hypotheses. 2020; 11:112.

40. Sadek SA. Comparative study clarifying the usage of PEEK as suitable material to be used as partial denture attachment and framework. Maced. J. Med. Sci. 2019;7:1193–7.

41. ELsyad MA, Kabil AAEG, Mekawy N El. Effect of implant position and edentulous span length on stresses around implants assisting claspless distal extension partial overdentures: An in vitro study. J. Oral Implantol.2017;43:100–6.

42. ELsyad MA, Omran AO, Fouad MM. Strains Around Abutment Teeth with Different Attachments Used for Implant-Assisted Distal Extension Partial Overdentures: An In Vitro Study. J.Prosthodont. 2017; 26:42–7.

43. Abouelleil H, Jeannin C, Sadat A, Grosgogeat B. Development of a chewing simulator for testing dental materials: A pilot study. Br. J. Appl. Sci.Technol. 2015;5:1–8.

44. Gülsen Can, Baransel Özmumcu, Pinar Altinci. In vitro Retention Loss of Attachment-retained Removable Partial Denture. J. Contemp. Dent. Pract. 2013; 14:1049-53

45. Hamada Zaki Mahross, Kusai Baroudi. Evaluation of Retention and Wear Behavior for Different Designs of Precision Attachments. Oral Health Dent. Manag. 2015;14: 244-9.

46. Mahabad Mahmud Saleh, Dhia Aldori. Assessment of retention characteristics of different attachments following new modifications (an in vitro study) Erbil Dent. J.2022;5: 9-18

47. Gonca Deste Gokay, Serhat Emre Ozkir, Thomas Gerhard Wolf, Gulsum Gokcimen, Nergiz Rona, Mehmet Bicer and Burak Yilmaz. The Effect of Denture Cleansing Solutions on the Retention of Precision Attachments: An In Vitro Study. Int. J. Envir Res.Public Health 2022, 19: 4345-8.

48. Nina Lümkemann , Monika Strickstrock , Marlis Eichberger , Isabella-Maria Zylla , Bogna Stawarczyk. Impact of air-abrasion pressure and adhesive systems on bonding parameters for polyetheretherketone dental restorations. Int. J. Adhes. Adhes. 2018; 80: 30-8.

49. Mahmoud El Moutassim-Bellah El Homossany and Hebatallah Tarek Abdallah.Comparative stress analysis study of CAD/CAM milled peek and zirconia primary copings in double crown peek framework mandibular partial denture after 1year simulated function. Egypt. Dent. J.2023;69: 639-51.

50. Ahmed Mostafa Abdelfattah Mohamed, Mahmoud El-Moutassem Bellah El Homossany, Sarah Mohamed Abdel moniem and Tariq Yehia Abdelrahman. Comparison of tensile bond strength of ball attachments made of different materials to root canal dentin after chewing simulation. BMC Oral Health. 2022; 22:254.

51. Rania Ramadan, Yasmine Elsherbeeny, Yasmine Thabet, Bassem Kandil, Rami Ghali. Retention of a telescopic overdenture on customized abutments after the simulation of 1 year in function. Dent. Med. Probl. 2021; 58:201–6.

52. Nesreen El Mekawy and Mohamed Elgamal. Retention Assessment of High Performance Poly-etheretherketone Removable Partial Denture Frameworks Constructed by Various Techniques (in vitro Study). J. Dent. (Shiraz). 2021 Dec; 22: 281–9.

53. Satyabodh S Guttal, Ramesh K Nadiger, Sagar Abichandani. Effect of Insertion and Removal of Tooth Supported Overdentures on Retention Strength and Fatigue Resistance of Two Commercially Available Attachment Systems. Int. J. Prosthodont. Restor. Dent. 2012; 2:47-51.

54. Wang HY, Zhang YM, Yao D, Chen JH. Effects of rigid and nonrigid extra coronal attachments on supporting tissues in extension base partial removable dental prostheses: a nonlinear finite element study. J. Prosthet. Dent. 2011; 105:338-46.

55. Peršić S, Kranjčić J, Pavičić DK, Mikić VL ČA. Treatment Outcomes Based on Patients' Self-Reported Measures after Receiving New Clasp or Precision Attachment Retained Removable Partial Dentures. J.Prosthodont. 2017; 26: 115–22.

56. Ahmed B. El-Okl , Mahmoud EL Samahy, Hatem K. El Din Amin and U. A. Khashaba. Stresses Induced By Integrated and' Nonintegrated Extracoronal Semi-Precision Attachments For Maxillary Distal Extension Bases. Al-Azhar Dent. J.Girls.2018;5:297-304.

57. Gupta, N., Bhasin, A., Gupta, P., and Malhotra, P. Combined prosthesis with extracoronal castable precision attachments. Case reports in dentistry, 2013, 282617.

58. Alghazzawi TF. Advancements in CAD/CAM technology: Options for practical implementation. J. Prosthodont. Res.2016; 60:72-84.

59. Stewart Kl, Rudd KD, Kuebker WA. Clinical removable partial prosthodontics. 2nd ed. Ishiyaku Euro America, USA. 1998.

60. Ahmed M Abdelhamid, Faten S Abbas, Mervat E Abd Ellah. Integrated versus non integrated reciprocation of attachment used for mandibular distal extension bases. Journal of Dental Health Oral Disorders & Therapy, 2017, 6 :135-42.

61. M Saito 1, Y Miura, K Notani, T Kawasaki. Stress distribution of abutments and base displacement with precision attachment- and telescopic crown-retained removable partial dentures. J Oral Rehabil. 2003 May;30:482-7.

62. Grasso, J. E., Miller, E. L. Removable Partial Prosthodontics. 3rd ed. United Kingdom: Mosby Year Book. 1991.

63. Da Cruz, M.B.; Marques, J.F.; Peñarrieta-Juanito, G.M.; Costa, M.; Souza, J.C.M.; Magini, R.S.; Miranda, G.; Silva, F.S.; Caramês, J.M.M.; da Mata, A. Bioactive-Enhanced Polyetheretherketone Dental Implant Materials: Mechanical Characterization and Cellular Responses. J. Oral Implantol. 2021; 47: 9–17.

64. Saleh N. Almohammed, Belal Alshorman and Layla A. Abu-Naba'a. Mechanical Properties of Five Esthetic Ceramic Materials Used for Monolithic Restorations: A Comparative In Vitro Study. Ceramics.2023; 6: 1031–49.

65. Marisa Aparecida de Souza, Bárbara de Oliveira Fiorin ,Tomaz Manabu Hashimoto, Ana Paula Rosifini, Carlos Angelo Nunes, Carlos Antônio Reis Pereira Baptista and Alfeu Saraiva Ramos. Influence of Niobium or Molybdenum Addition on Microstructure and Tensile Properties of Nickel-Chromium Alloys. Metals. 2019; 9:589.

66. Najeeb S, Zafar MS, Khurshid Z, Siddiqui F. Applications of polyetheretherketone (PEEK) in oral implantology and prosthodontics. J.Prosthodont.Res.2016;60:12–9.

67. Zoidis P, Papathanasiou I, Polyzois G. The use of a modified poly-etherether-ketone (PEEK) as an alternative framework material for removable dental prostheses. A clinical report. J.Prosthodont. 2016; 25:580–4.

68. Rodolfo Reda, Alessio Zanza , Massimo Galli, Alberto De Biase , Luca Testarelli and Dario Di Nardo. Applications and Clinical Behavior of BioHPP in Prosthetic Dentistry: A Short Review. J. Compos. Sci. March 2022; 6: 90.

69. Rutkunas V, Mizutani H, Takahashi H, et al. Wear simulation effects on overdenture stud attachments. Dent. Mater. J. 2011; 30: 845–53.

70. Marin DOM, Leite ARP, de Oliveira Junior NM, et al. Retention force and wear characteristics of three attachment systems after dislodging cycles. Braz. Dent. J.2018; 29: 576–82.

71. Ronald Sakaguchi, Jack Ferracane, John Powers. Craig's Restorative Dental Materials. In : Polymers; 14th ed., p 116, 2019. ElSevier , 3251 Riverport Lane St. Louis.

72. Bogna Stawarczyk, Christin Keul, Marlis Eichberger, David Figge, Daniel Edelhoff, Nina Lümkemann. Three generations of zirconia: From veneered to monolithic. Part I. Quintessence Int. 2017;48: 369-80.