Induced Strain of Different Extra-Coronal Attachment Materials in Mandibular Kennedy Class I Metallic Removable Partial Dentures After One Year of Clinical Simulation: An in-Vitro study

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Research Article

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Abstract

Background: The strain developed by different extra-coronal attachment materials during loading in aqueous environment as well as the effect of denture insertion and removal cycles is of prime importance. Accordingly, the aim of the current study was to assess the induced strain of different extra-coronal attachment materials in mandibular Kennedy class I metallic removable partial dentures after one year of clinical simulation.

Methods: Twelve identical 3D-printed models representing mandibular Kennedy class I with first premolars as principal abutments bilaterally were fabricated having 4 removable dies each; canine and first premolar on which two splinted crowns with three different extra-coronal attachment materials (group A: PEEK/BioHPP, group B: zirconia, group C: metal)were fabricated bilaterally. Each of the 3D-printed models (n=4 for each group) was designed with four strain gauge slots, two on each side: 1mm distal to the first premolar (SG1 &SG3) and 1 cm away from the first one at the edentulous ridge (SG2&SG4). Removable partial dentures were constructed, and strain gauges were used to measure the strain applied both unilaterally and bilaterally by a universal testing machine before and after one year of clinical simulation where, an average of 5 readings were recorded for each model. Clinical simulation was performed through chewing simulator and dentures insertion/removal cycles. Repeated measures ANOVA and Tukey's post-hoc test were used for data analysis at $p < 0.05$.

Results: PEEK (BioHPP) group revealed the lowest induced strain before and after one year of clinical simulation compared to zirconia and metal groups during both unilateral and bilateral loading with significantly higher induced strain at SG2 & SG4 compared to that induced at SG1 & SG3. Metal group showed the same pattern but with significantly higher values compared to PEEK (BioHPP). For zirconia group after one year of clinical simulation, bilateral loading revealed significant decrease in induced strain at SG1&SG3 with a significant increase at SG2 &SG4.

Conclusions: PEEK (BioHPP) is more effective in stress dissipation as an extra-coronal attachment in removable partial dentures compared to zirconia and metal. After one year of clinical simulation.

BACKGROUND

Prosthetic management of bilateral distal extension removable partial denture (RPD) cases classified as Kennedy class I has always been a challenging situation for dental practitioners [1]. Different treatment modalities have been implicated for rehabilitation of partially edentulous cases including clasp retained or attachment retained removable partial dentures (RPDs) as well as dental implant supported prosthesis [2, 3]. Lack of retention, stability, high liability for dental caries and periodontal diseases as well as the unaesthetic appearance of the clasps are among the common clinical problems associated with clasp retained RPDs [4–7]. Though dental implants can be used to overcome many of the problems associated with RPDs yet, their use is limited by the systemic condition of the patient, bone factors and economic status [8, 9].

Attachment retained RPDs offer improved retention and esthetics when compared to clasp retained ones [10, 11]. Moreover, they are less liable to fracture than clasps, have less bulk as well as reduced incidence of secondary caries [12–15]. An attachment is defined as a mechanical device for fixation, retention and stabilization of a prosthesis [16]. The extra-coronal resilient attachments consist of two components; resilient and rigid parts that allow articular, rotational and frictional movements. The rigid positive component is the patrix which is generally located on the crown restoration made upon abutment teeth while the resilient one is the negative component which is the matrix usually incorporated into the removable prosthesis [17,18]. Resilient extra-coronal attachments have been indicated for distal extension base cases to prevent torque of abutments and to distribute load favorably between abutments and the edentulous ridge. It has been reported that stresses on the terminal abutment can be reduced by the use of an extra-coronal resilient attachment that allocates more load onto the distal edentulous ridge [19]. To reduce the stresses caused by extra-coronal attachments, abutments should be splinted with full coverage retainers[20–22]. They are considered more conservative than intra-coronal ones as they involve less teeth preparation [14].

One of the most commonly used materials for fabrication of semi-precision attachments is nickel chromium alloy. Nickel chromium has shown good clinical results when used with attachments and porcelain fused to metal fixed partial dentures due to its high modulus of elasticity, hardness, relatively low cost, and convenient laboratory procedures [23–24].

On the other hand, zirconia revealed far superior mechanical properties among all other prosthetic ceramic materials that is comparable to metals utilized in metal-ceramic fixed prostheses. Zirconia provides high strength, biocompatibility, good aesthetics, low thermal conductivity, chemical inertness as well as high fracture toughness, flexural strength and hardness [25,26]. Zirconia has been applied in primary telescopic crowns, full and partial coverage fixed restorations, inlays, onlays, posts as well as implants, implant attachments and abutments. Currently, there are several types of zirconia attachments available for retention of removable partial dentures including extra-coronal attachments, a ball attachment for overdentures as a component of a zirconia post as well as bar attachments. Yet, literature lacks sufficient data regarding the use of zirconia as an extra-coronal precision attachment to support a cast metal partial denture prosthesis [25–27].

Moreover, polyether ether ketone (PEEK) has been introduced in dental applications. Compared to metals used in dentistry, PEEK has elastic modulus close to human enamel and dentin. It is lighter in weight, has high thermal stability and good esthetics [28]. In addition, PEEK is biocompatible that showed no evidence of cytotoxicity, carcinogenicity or immunogenicity and the creation of biofilm on its surface is equal to or even lower than other dental materials such as titanium and zirconia [29]. However, the fracture resistance of PEEK is still unsatisfactory which led to the development of a modified form of PEEK known as Bio-HPP. [30] Bio-HPP which stands for Bio high performance polymer is considered one of the variants of PEEK that contains about 20% ceramic fillers. It was first developed by Bredent GmbH and has been optimized especially for dental applications because of its superior properties. The addition of special small ceramic fillers with a grain size between 0.3 to 0.5 microns results in constant homogeneity, extremely good polishing properties and high mechanical properties [30,31].

The recent, rapidly developing advances in computer aided design and computer aided manufacturing (CAD/CAM) has simplified the use of new different materials which could be accurately milled for the construction of planned dental prosthesis. CAD/CAM systems comprise a digitalization tool (scanner) which converts geometry into digital data that can be managed by the computer, software for data processing and a production technology that converts the data set into the required product [32,33]. Dental restorations manufactured using CAD/CAM technology have become widespread in recent years attributed to the fast production due to the automated manufacturing procedures. CAD/CAM allows the use of variety of materials for different types of dental prosthesis [33].

Understanding the difference in nature and behaviour of the tissues supporting RPD is critical for long term success of the prosthesis. These differences together with the function, create major stresses on the tooth-tissue prostheses. Moreover, abutment teeth and the supporting structures of the prosthesis, are not only subjected to stresses during function but also during insertion and removal. If this stress exceeds their natural resistance, it will result in resorption in the supporting alveolar bone, loss of the abutment and eventually, failure of the prosthesis [34]. In the same way, the free-end saddle cases are subjected to stresses during function, resulting in bone resorption, loss of the support, and loss of stability of the prostheses, which necessitate frequent replacement [35,36].

Different methods have been applied for measuring stresses induced in abutment teeth, surrounding structures and prostheses [37]. Among the common stress analysis methods are the electrical strain gauges. Strain gauges can be used for both in vivo and in vitro measurements of strain induced under static or dynamic loading. It has been extensively used in stress analysis studies with different prosthodontic appliance designs [20,37,38].

Strain gauges are small electric resistors that rely on changing the electrical resistance with changes in strain that results from an applied stress. The captured electrical signal is sent to a data acquisition board, turned into a digital signal, and read by the computer. The gauges are able to precisely record the deformation of any object subjected to stress [37,38]. Many studies were conducted on stress analysis for extra-coronal attachments using strain gauges. They examined the stresses unilateral, bilateral or both [39–42].

Moreover, in order to evaluate dental materials as close as possible to the oral environmental conditions, chewing simulators have been used in an attempt to replicate dynamic mandibular movements that mimic normal masticatory function. The chewing simulator operates through an antagonist that strikes a specimen with specific parameters using a predetermined weight. A variety of motion patterns can be programmed in order to simulate various mandibular movements [43].

Many studies investigated the effect of different materials and designs of extra-coronal attachments on the strain induced and transmitted by RPDs to the supporting structures [10–13,24,39,40]. Other researchers assessed the effect of insertion and removal cycles and simulated occlusal loading on the retention of extra-coronal attachment retained RPDs [44–47]. Yet, literature lacks sufficient information regarding the effect of simulated aging on different extra-coronal attachment materials as retainers for RPDs under different environmental conditions on the strain induced and transmitted by RPDs to the supporting structures.

Based on the previously reviewed literature, it should be emphasized that the strain developed by different extra-coronal attachment materials like PEEK (BioHpp), zirconia and metal under different environmental conditions including loading in an aqueous environment in addition to the effect of the insertion and removal cycles of the denture is of crucial importance.

Accordingly, the aim of the current study was to assess the strain induced by PEEK (BioHPP), zirconia and metallic extra-coronal attachments under different environmental conditions including the combined effect of dynamic loading in aqueous environment in addition to the effect of denture removal and insertion cycles simulating one year of clinical service. The first null hypothesis tested was that there would be no difference in the strain induced by the three extra-coronal attachment materials. The second null hypothesis was that there would be no difference in the strain generated as a result of aging in simulated oral conditions (dynamic loading in aqueous environment and removal and insertion cycles of the denture) equivalent to one year of clinical service.

Methods

Study design and grouping

Twelve experimental models representing mandibular Kennedy class I with first premolar as a principal abutment bilaterally were constructed having 4 removable dies each (canine and first premolar bilaterally). The experimental design involved 3D printed models that were randomly assigned into three groups according to the material of the extra-coronal attachment material used where each group included 4 models. Group A involved PEEK (BioHPP) extra-coronal attachment retained RPDs, Group B involved zirconia extra-coronal attachment retained RPDs, while group C received full veneer metal ceramic retainers with a metallic extra-coronal attachment retained RPDs.

The planned design was two splinted crowns on the canine and first premolar with extra-coronal attachments bilaterally. A lingual bar major connector and combined denture base were applied in the current study. For each model, the average of five measurements of strain values (um/m) was calculated for each extra-coronal attachment retained RPD.

Fabrication of the experimental models

For fabrication of the experimental models, an educational mandibular Kennedy class I model was used with the first premolar being the last standing abutment bilaterally. The model was scanned by desktop scanner (DOF swing desktop scanner, Seoul, South Korea), where it was fixed to the desktop scanner plate and sprayed with occlusion spray (Titanium dioxide-free spray) for identifying any trouble spots during scanning. Order for scanning was performed and a standard tessellation language (STL) file was generated on the software (Exocad Dental CAD, Exocad Inc. Darmstadt, Germany). On the software, designing and modifying the virtual model was performed.

Designing and modification of the virtual model and preparation of the virtual abutments

The virtual model was modified to have four abutments in the position of the mandibular canine and first premolar bilaterally. The abutment teeth were removed on the software from their sites on the virtual model to be prepared separately giving an STL file for the prepared dies only. This STL file was used later for superimposition of the prepared abutments in their corresponding sockets in the previously scanned mandibular model.

The design for abutments' preparation was selected from the software library so that, they are perpendicular to the occlusal plane with common path of insertion and removal. The prepared abutments had deep chamfer finish lines 1.5 mm in thickness to be ready to receive two splinted crowns bilaterally with extra-coronal attachments having common path of insertion. A thickness of 2 mm layer was cut back from the crest of the scanned model for mucosa simulation. A space of 0.25 mm was left between the inner surface of the sockets of the canines and first premolars simulating the periodontal membrane space (Figs. 1–3).

Four strain gauge slots, two on each side, were designed on the software to receive the strain gauge rosettes. The first one (slot I) was prepared 1mm distal to the socket of the first premolar and the second slot (slot II) located 1 cm away from the first one. The slots were made parallel to each other with dimensions 2 mm mesiodistal, 5.5mm buccolingual and 5mm occluso-gingival (Fig. 4).

This was followed by exporting the STL files to the additive manufacturing device. The printing machine (Form 2 3D printer, Form labs, Somerville, Massachusetts, United States) was used to print the models and the removable dies. For each model, printing was performed layer by layer via UV light projection to achieve polymerization of the layers from base to top until the whole model and removable dies were printed (Fig. 5). Printing of models and dies were performed using model resin material (Pro shape dental cast resin, Turkey). For each of the prepared models, two identical sets of separated dies were printed and checked in their sockets on the right and left sides of the 3D model.

Gingival simulation

Gingival simulation was performed by building up modelling wax on the 3D model over the 2 mm designed space for mucosal simulation to mimic the viscoelastic behavior of the muco-periostium covering the residual ridge. Soft tissue-simulating material (Affinis, light body rubber base, Coltene Whaledent) was applied onto the printed models using a transparent vacuum-produced vinyl stent to replicate the mucosa, guided by the remaining teeth.

Fabrication of the crowns and their attachments

Each 3D printed model with the mucosal simulation and prepared abutments (mandibular canine and first premolar bilaterally) were scanned to generate STL file for virtual designing of two fully anatomical splinted crowns on the prepared abutments. The virtually designed bilateral splinted crowns were checked occluso-gingivally, bucco-lingualy and mesio-distally for proper dimensions with smoothening of all surfaces of the crowns to avoid any sharp undesirable areas. The attachments were chosen from the library, attached to the distal wall of the first premolar crown bilaterally on a line bisecting the angle between the crest of the ridge and the sagittal plane with 1mm space occlusally. The extra-coronal attachment used was an OT-strategy with a standard male part of 1.8 mm sphere (Rhein 83, Bologna, Italy). This was followed by sending the standard tessellation format (STL file) to the subtractive manufacturing device (DWX-52D, Ronald DGA, California, USA) to fabricate the splinted crowns with the intended extra-coronal attachment as follows:

For group A

The splinted crowns and attachments were milled out of PEEK (BioHPP) (blank size 14, Brecam BioHPP, Bredent, Germany) then checked for perfect fit with prepared abutments. The bonding surfaces of PEEK (BioHPP) retainers were ultrasonically cleaned in distilled water for 10 minutes after being abraded with 50 µm Al_2O_3 airborne particles (0.2 MPa at 10 mm distance for 10 s) [48] and the bonding surfaces of the dies with alcohol. Following the manufacturers' instructions; a primer Visio.link, (Bredent, Senden, Germany) was applied and the retainers were then cemented to the models with resin cement (Panavia V5, Kuraray Noritake Dental Inc., Tokyo, Japan) (Fig. 6).

For group B

The splinted crowns and extra-coronal attachments were milled out of zirconia

(Zolid Ceramill Amann Girrbach, GmBH, Germany) using the milling machine (Shera eco-mill 5x, Werkstoff-Technologie GmbH & Co. KG, Germany). The zirconia crowns were then sintered in a furnace (TABEO-1/M/ZIRKON-100, Mihm-Vogt,Germany) with the classic sintering system. All sintering parameters were strictly followed according to the manufacturer's instructions, sintering temperature 1650ºC, total process time 239 minutes, starting from room temperature. Following sintering, finishing, polishing and glazing for the crowns and attachments were performed. Zirconia crowns were then checked for perfect fit with the prepared abutments, surface treated and cemented in place with resin cement following the same procedure applied for PEEK (BioHPP) except for the primer used where, Panavia V5 Tooth Prime (Kuraray Noritake Dental Inc., Tokyo, Japan) was used for following the manufacturer's instructions (Fig. 7).

For group C

The patterns for PFM with the extra-coronal attachments were 3D printed with wax (Dental wax, Yamahachi MFG,Co, Japan). The wax patterns were then conventionally invested and casted in nickel-chromium (Magnum ceramic co, Mesa Italia, Travagliato, Italy), sandblasted, finished and polished except for the male portion of the attachment. The metal crowns were then checked for fitness with the abutment dies followed by firing of porcelain (VITA VMK Master Germany) to the metallic crowns, surface treated and cemented in place with resin cement following the same procedure applied for zirconia crowns **(**Fig. 8**).**

Removable Partial Denture Design and Fabrication

The RPD framework was designed utilizing the partial denture module of CAD/CAM design software. The STL files of the virtual models with the primary frameworks were used to design RPDs for the prepared models with the same design and thickness. Each RPD was designed with a combined denture base, and a lingual bar major connector. The resin patterns of the RPD frameworks were 3D printed using castable resin (NextDent B.V. Soesterberg, Netherlands), then invested and casted into cobalt-chromium (Wironium, BegoGmBH, Germany) using the conventional technique.

The frameworks were seated to ensure proper fit on their respective models. On each model, an initial RPD framework was waxed up. This was followed by setting the acrylic resin teeth (Acrostone acrylic teeth, Vitamisr Lab, Egypt). To standardize the denture base thickness and position of the teeth in the RPDs, a rubber index mold (Dental Products 3M Center Building, St. Paul, USA) was formed on the waxed-up RPD. The waxed-up RPDs were then flasked and processed into heat-cured acrylic resin (Acrostone, Egypt.) to fabricate identical RPDs. The attachment housings were picked-up into the fitting surfaces of the RPDs using a cold-cured acrylic resin (Acrostone, Egypt).

Testing procedures

Strain gauge installation and strain analysis

The strain gauges (Kyowa- Electronic Instruments Co, LTD, Tokyo, Japan.) used in this study had a length of 1 mm, resistance of 119.6 ± 0.4 Ω and a gauge factor of 2.13% ±1.0. All strain gauges were mounted on the prepared sites of the printed model, parallel to the long axes of the abutments, using a fast-setting cyanoacrylate adhesive (Pattex super glue, Henkel, Germany).

The strain gauges were connected to a four-channel strain indicator (Strain meter PCD-300 A Kyowa Electronic instruments Co) to measure the microstrain induced by the applied load.

The model was placed on the lower metal plate of the universal testing machine. A static load was applied through a load applicator attached to the upper compartment of a universal testing machine (Lloyd LRX; Lloyd Instruments Ltd., Fareham, UK) at a crosshead speed of 0.5mm/min until a load of 100 N, at which instant, the resultant strain was calculated.

The load was applied both unilaterally and bilaterally. For unilateral loading, a rod-shaped load applicator was used. The location of load application for unilateral loading was chosen to be the central fossa of the first molar on the left side (loading side) (Fig. 10). For bilateral loading, a rectangular metal bar with a small depression demarcated at its center was placed on the occlusal plane between the right and left sides of the denture base in the region of the first molar. The load was applied at the center of the metal bar using the load applicator attached to the upper compartment of the universal testing machine (Fig. 11). The average of five measurements was recorded for each reading with at least five minutes between each measurement. The mean values of the recorded strain were collected, tabulated, and statistically analyzed.

Aging procedures

For simulation of the oral environment, a chewing simulator (CS-4.4; SD Mechatronic, Germany) was used. After painting the mounting ring of the chewing simulator with Vaseline, each model was placed so that the load applicator was positioned in the center of the metal bar. The model was then secured in place using self-cured acrylic resin. The setting parameters of the chewing simulator were adjusted (60 mm/s, 3 mm vertical path, 0.7 mm horizontal path, 1.6 Hz frequency, 50 N) [49].

The chambers of the chewing simulator were filled with artificial saliva prepared in the pharmaceutical industry lab, Faculty of Pharmacy, Ain-Shams University according to the formula adopted from Glandosane®; Fresenius Kabi Ltd, Germany [49,50]. Bi-axial cyclic loading of 240000 cycles at room temperature were applied to each model simulating one year of clinical service [49–51] (Fig. 12).

Based on the assumption that under regular conditions, a patient inserts and removes his denture with an average of four cycles/day (after every meal and before sleep time), A total of 1440 insertion/removal cycles were applied for each partial denture corresponding to one year of clinical service. [51–53] This was followed by mounting each model with the corresponding partial denture again in the universal testing machine to assess the induced strain at the abutments and the edentulous ridge.

Statistical analysis

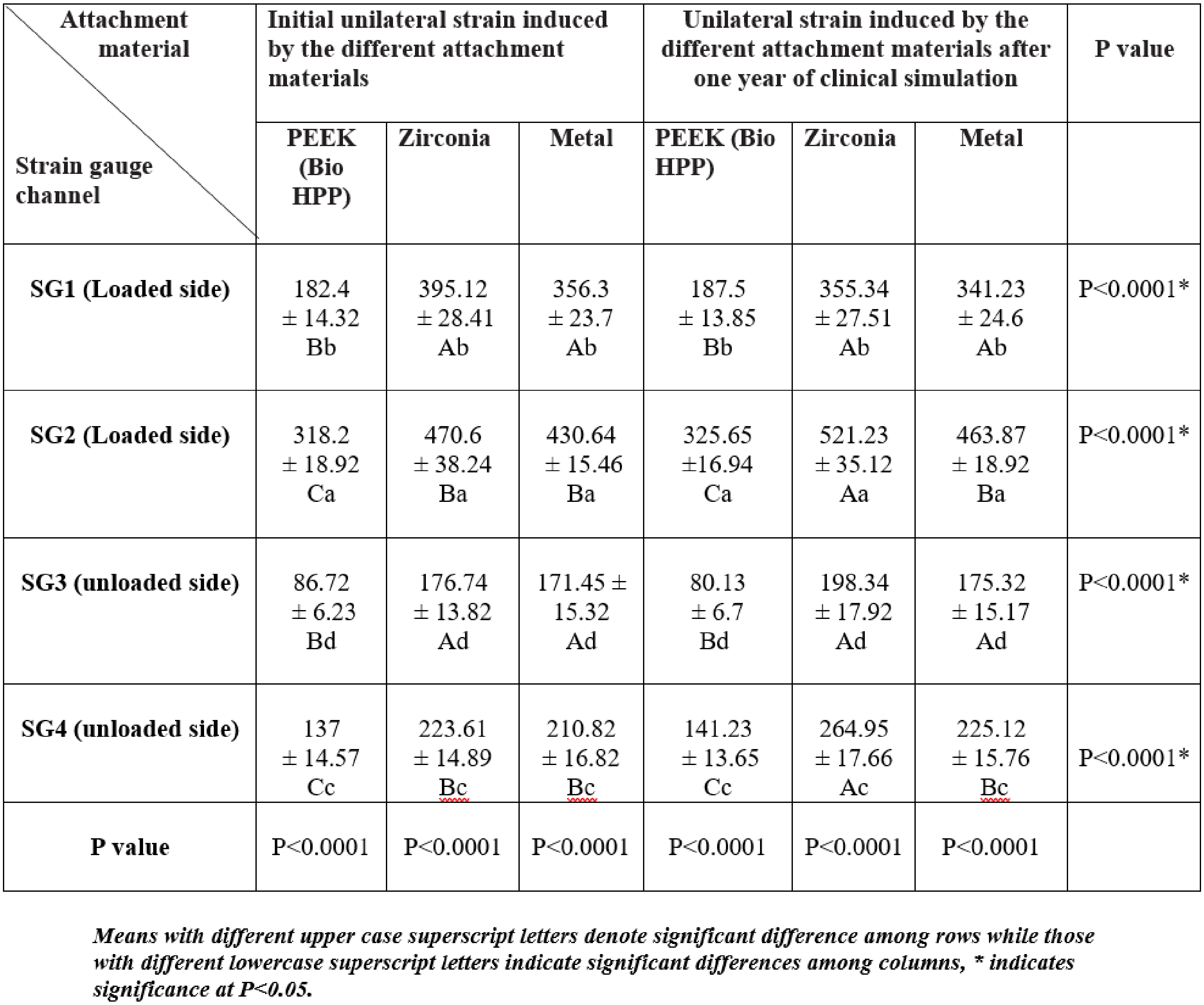
SPSS statistical package for social sciences version 22 (SPSS Inc., Chicago, IL) was used for data analysis. Data were tested for normality using Kolmogorov-Smirnov and Shapiro-Wilk test. The explored data showed normal distribution and were represented as mean and standard deviation (SD) values. Repeated measures ANOVA test was applied to assess the effect of different extra-coronal attachment materials as well as the effect of one year of clinical simulation on the induced strain for the different tested groups. For pairwise comparison, Tukey’s post-hoc test was applied. The significance level was set at $p < 0.05$.

Results

Repeated measures ANOVA revealed a significant effect for the material used for extra-coronal attachment as well as the effect of one year of clinical simulation. Moreover, the interaction between the two variables was significant (P > 0.0001). Comparing the induced strain during unilateral loading before and after one year of clinical simulation revealed significantly higher values at SG1 and SG3 (distal to the abutments) for zirconia and metal groups compared to PEEK (BioHPP) for both loaded and unloaded sides with insignificant difference between both zirconia and metal groups.

However, SG2 and SG4 (strain induced on the edentulous ridge) on the loaded and unloaded sides respectively recorded the highest significant mean value for zirconia group after one-year clinical simulation while the lowest mean strain values were recorded by PEEK (BioHPP) groups. Both PEEK (BioHPP) and metal groups showed insignificant differences in mean strain induced before and after one year of clinical simulation. Intragroup comparisons for the tested materials revealed a similar pattern where the highest significant mean strain value was recorded at SG2, followed by SG1, SG4 and the lowest value at SG3 with statistically significant differences between the mean strain values recorded at the 4 strain gauges (Table 1 & Fig. 13).

Table 1: Means ± standard deviation values and significance of the induced strain (um/m) distal to the abutments and the distal edentulous ridge for the three tested attachment materials during unilateral loading before and after 1 year of clinical simulation.



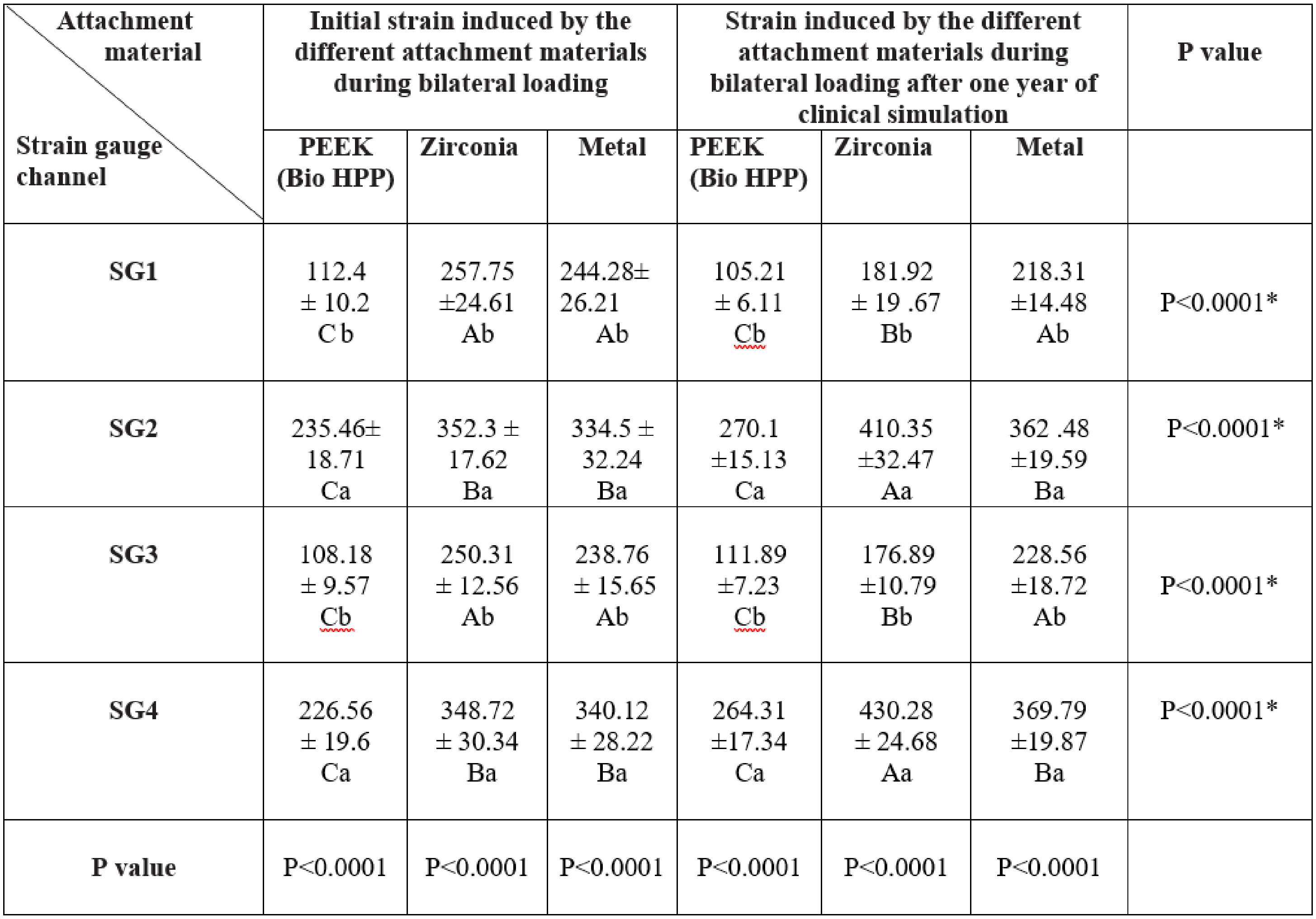
Attachment material / Strain gauge channel	Initial unilateral strain induced by the different attachment materials			Unilateral strain induced by the different attachment materials after one year of clinical simulation			P value
	PEEK (Bio HPP)	Zirconia	Metal	PEEK (Bio HPP)	Zirconia	Metal	
SG1 (Loaded side)	182.4 ± 14.32 Bb	395.12 ± 28.41 Ab	356.3 ± 23.7 Ab	187.5 ± 13.85 Bb	355.34 ± 27.51 Ab	341.23 ± 24.6 Ab	P<0.0001*
SG2 (Loaded side)	318.2 ± 18.92 Ca	470.6 ± 38.24 Ba	430.64 ± 15.46 Ba	325.65 ±16.94 Ca	521.23 ± 35.12 Aa	463.87 ± 18.92 Ba	P<0.0001*
SG3 (unloaded side)	86.72 ± 6.23 Bd	176.74 ± 13.82 Ad	171.45 ± 15.32 Ad	80.13 ± 6.7 Bd	198.34 ± 17.92 Ad	175.32 ± 15.17 Ad	P<0.0001*
SG4 (unloaded side)	137 ± 14.57 Cc	223.61 ± 14.89 Bc	210.82 ± 16.82 Bc	141.23 ± 13.65 Cc	264.95 ± 17.66 Ac	225.12 ± 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 difference among rows while those with different lowercase superscript letters indicate significant differences among columns, * indicates significance at P<0.05.

Comparing the induced strain during bilateral loading before and after one year of clinical simulation revealed that the lowest mean strain values were recorded by PEEK (Bio HPP) group before and after one year of clinical simulation with insignificant difference between the mean recorded strain values. After one year of clinical simulation, zirconia group showed significant decrease in the mean induced strain at SG1 and SG3 (distal to the abutments). On the other hand, a significant increase was recorded at SG2 and SG4 (at the edentulous ridge). Metal group showed insignificant difference before and after one year of clinical simulation. Pairwise comparisons within each group revealed significantly higher mean strain values at SG2 and SG4 compared to SG1 and SG3. Statistical analysis showed insignificant differences between the mean strain values recorded at SG2 and SG4 as well as between SG1 and SG3 (Table 2 & Fig. 14).

Table 2: Means ± standard deviation values and significance of the induced strain (um/m) at the abutment and the distal edentulous ridge for the three tested attachment materials during bilateral

loading before and after 1 year of clinical simulation.



Attachment material / Strain gauge channel	Initial strain induced by the different attachment materials during bilateral loading			Strain induced by the different attachment materials during bilateral loading after one year of clinical simulation			P value
	PEEK (Bio HPP)	Zirconia	Metal	PEEK (Bio HPP)	Zirconia	Metal	
SG1	112.4 ± 10.2 C b	257.75 ±24.61 Ab	244.28± 26.21 Ab	105.21 ± 6.11 Cb	181.92 ± 19 .67 Bb	218.31 ±14.48 Ab	P<0.0001*
SG2	235.46± 18.71 Ca	352.3 ± 17.62 Ba	334.5 ± 32.24 Ba	270.1 ±15.13 Ca	410.35 ±32.47 Aa	362 .48 ±19.59 Ba	P<0.0001*
SG3	108.18 ± 9.57 Cb	250.31 ± 12.56 Ab	238.76 ± 15.65 Ab	111.89 ±7.23 Cb	176.89 ±10.79 Bb	228.56 ±18.72 Ab	P<0.0001*
SG4	226.56 ± 19.6 Ca	348.72 ± 30.34 Ba	340.12 ± 28.22 Ba	264.31 ±17.34 Ca	430.28 ± 24.68 Aa	369.79 ±19.87 Ba	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 difference among rows while those with different lowercase superscript letters indicate significant differences among columns, * indicates significance at P<0.05.

Discussion

Attachments as RPD retainers are one of the considerable treatment options for enhancing the esthetic outcome [20,23] as well as providing more favorable stress distribution for natural teeth and periodontal protection compared to the conventional approach that relies on clasp retainers [34,54]. The current study was designed with Kennedy class I RPD with two splinted crowns on the canine and first premolar on each side of the edentulous arch as it had been recommended to involve at least two abutment teeth in distal extension cases to reduce stresses induced on the abutment teeth. [20,55] An extra-coronal semi-precision attachment with nylon caps as a retentive matrix in the denture base of the RPD was used to impart resiliency and subsequently allow for stress breaking effect [55,56].

Three- dimensional models were digitally printed to allow standardization between the test groups. In addition, digital designing is less time consuming, provides high accuracy and less manufacturing errors compared to the conventional technique [24,57]. Moreover, digital designing allowed standardized placement of the strain gauge slots in relation to the abutments than manual placement, with even and smooth surface that minimizes the possibility of recording strain as a result of rough surfaces. In an attempt to mimic the viscoelastic behavior of the periosteum overlying the residual ridge, mucosal simulation was performed with 2 mm approximate thickness. Addition silicone rubber base impression material has been used attributed to its low dimensional changes, minimal permanent deformation and less time required to recover the viscoelastic deformation compared to other rubber base impression materials [38,48].

Strain gauges are considered one of the frequently used methods to evaluate the induced strain in different dental applications owing to their accuracy, small dimensions as well as minimal interference during testing procedures. In-vitro strain gauge studies remain as valuable guides to the clinicians attributed to the limitations of their use in the oral cavity that may include difficulty in isolation of the gauges from saliva and blood which could result in short circuits in addition to the possibility of patient’s movement resulting in wire movement and consequently inaccurate results [38,48].

The load applied for strain gauge measurement was about 100 N which corresponds to the average chewing force required for most types of food with about 15 minutes between each two successive measurements to allow complete rebound of the resilient structures [48]. The point of load application was selected at the central occlusal fossa of the first molar for unilateral loading as it is considered the center of occlusion [41]. For bilateral loading, a rectangular metal bar was placed on the occlusal plane between the right and left sides of the denture base in the first molar region. The metal bar was demarcated with a diamond bur at its center to standardize the position of load application and avoid any inadvertent movement of the applicator tip during measurements to ensure reliable results [24].

One of the factors that should be considered during evaluation of the induced stresses and the resulting strain of prosthetic appliances is their continuous exposure to various challenging stimuli including humidity and mastication in the oral environment in addition to the influence of repeated insertion and removal of the appliance. In-vitro simulation of such conditions could be helpful when evaluating the mechanical behavior and longevity of different prosthetic appliances [43–45]. Therefore, the study was designed to assess the induced strain after application of dynamic loading by a chewing simulator in both axial and lateral movements and in presence of artificial saliva as an aqueous media, in addition to the insertion and removal cycles of the denture equivalent to one year of clinical service.

Based on the results obtained in the current study, the first null hypothesis was rejected as there was a significant difference in the strain induced by the three extra-coronal attachment materials. Statistical analysis revealed that PEEK (Bio-HPP) showed the lowest amount of induced strain compared to zirconia and metal extra-coronal attachments in both unilateral and bilateral loading. This could be explained based on the lower elastic modulus of BioHPP (3-4GPa) [58] compared to zirconia (≥ 200 GPa) [59] and nickel chromium (190 GPa) [60] which have much higher modulus compared to that of human cortical bone (14 GPa) [58]. The close matching in the elastic modulus of BioHPP and human bone results in better stress distribution. The shock absorbing property of BioHPP due to its resiliency has a cushioning effect that helps to reduce the stresses transferred to the abutment teeth and their supporting structures [61–63]. Moreover, the relatively close elastic modulus values for both zirconia and metal could further explain the insignificant difference in the induced strain between the two groups before one year of clinical simulation in both unilateral and bilateral loading conditions. This was in agreement with Nassouhy and Abdalla [23] who reported in their clinical study that zirconia attachment yields comparable clinical and radiographic results as metal attachments for distal extension cases within a follow-up period of one year.

Before clinical simulation, for all tested groups statistical analysis revealed significantly higher mean strain values at SG2 and SG4 (at the edentulous ridge) for bilateral loading and the loaded side of unilateral loading compared to those obtained at SG1 and SG3 (distal to the abutments). This could be attributed to the difference in compressibility between the abutment teeth and the resilient mucosa which results in rotational movement of the partial denture during load application Moreover, the leverage action generated by the ball attachment placed in the vicinity of the edentulous ridge could result in more stress concentration thus increasing the induced strain on the residual ridge. This was in agreement with ElAswad and Youssef [24] and Elsyad et al [41].

After one year of clinical simulation, stress distribution showed the same pattern for the RPDs of the three tested extra-coronal attachment materials except for zirconia group which showed the highest significant induced strain values at SG2 and SG4 (at the edentulous ridge) for both unilateral and bilateral loading. However, during bilateral loading, zirconia group showed significantly lower induced strain compared to metal group at both SG1 & SG3 (distal to the abutments). PEEK (BioHPP) group still revealed the lowest induced strain compared to other materials after one year of clinical simulation. Thus, the second null hypothesis was rejected.

The significant increase in the load transmitted to the edentulous ridge in zirconia extra-coronal attachment RPD after 240000 cycles in artificial saliva in the chewing simulator added to the effect of 1440 insertion and removal cycles of the RPDs could be attributed to the expected wear of the nylon cap (female part of the attachment) due to the high hardness of zirconia compared to that of the nylon cap which could result in wear of the nylon cap and loss of retention which consequently changes the pattern of stress distribution allowing for partial dissipation of the induced stresses distal to the abutments on bilateral loading and hence more stresses are transmitted to the residual ridge [64–67]. This explanation could further justify the manufacturer’s recommendation that the nylon cap should be annually replaced.

Conclusions

Within the limitations of this study, it could be concluded that PEEK (BioHPP) is more effective in stress dissipation as an extra-coronal restoration in attachment retained RPDs compared to zirconia and metal. Moreover, after one year of clinical simulation. Zirconia has a more detrimental effect on the stresses transmitted to the residual ridge compared to PEEK (BioHPP) while metal attachment maintained the same pattern.

Abbreviations

PEEK	Polyetheretherketone
RPD	Removable partial denture
STL	Standard tessellation language
Bio-HPP	Bio high performance polymer
CAD/CAM	Computer aided design and computer aided manufacturing .

Declarations

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Not applicable

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Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Ethical approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The author declares that he has no competing interests

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Figures

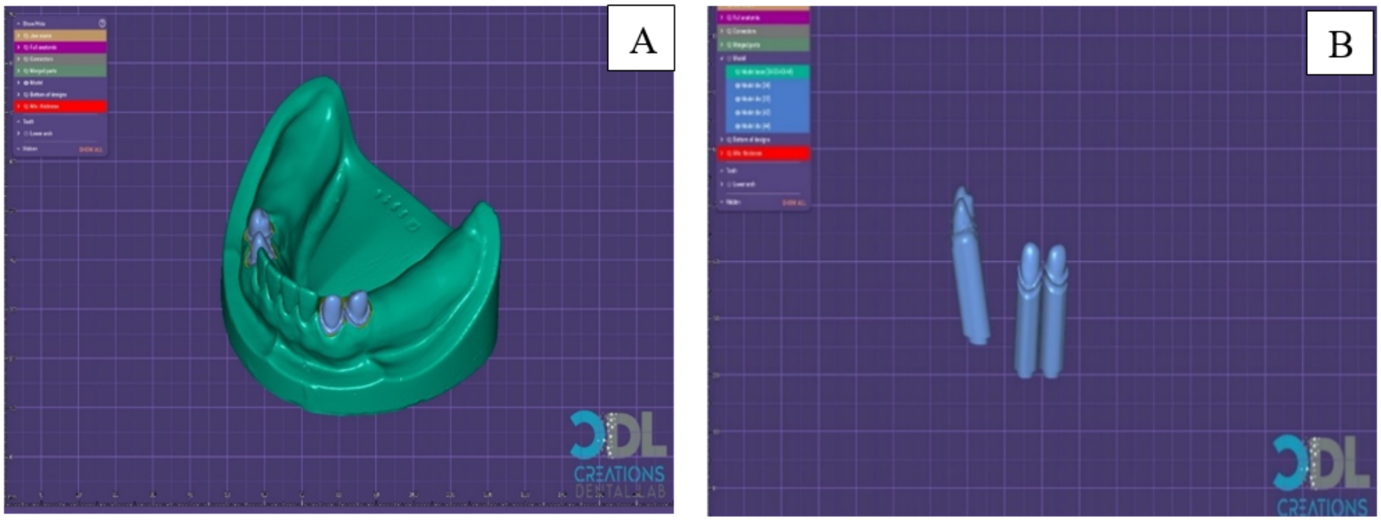

Figure 1

A-Virtual model with the prepared abutments. B: Prepared virtual abutments.

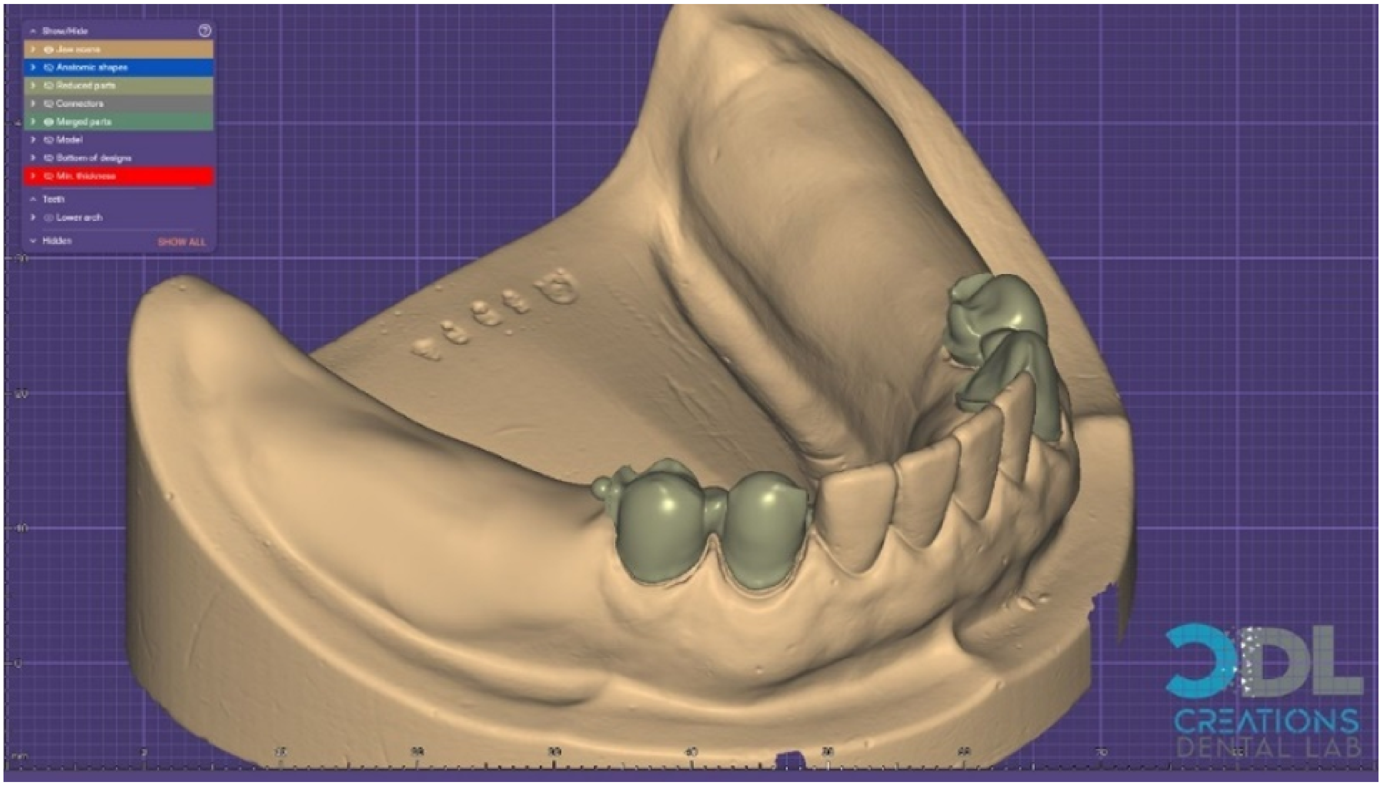

Figure 2

The scanned model with the designed pattern with cut-back for PFM crowns with extra-coronal attachments.

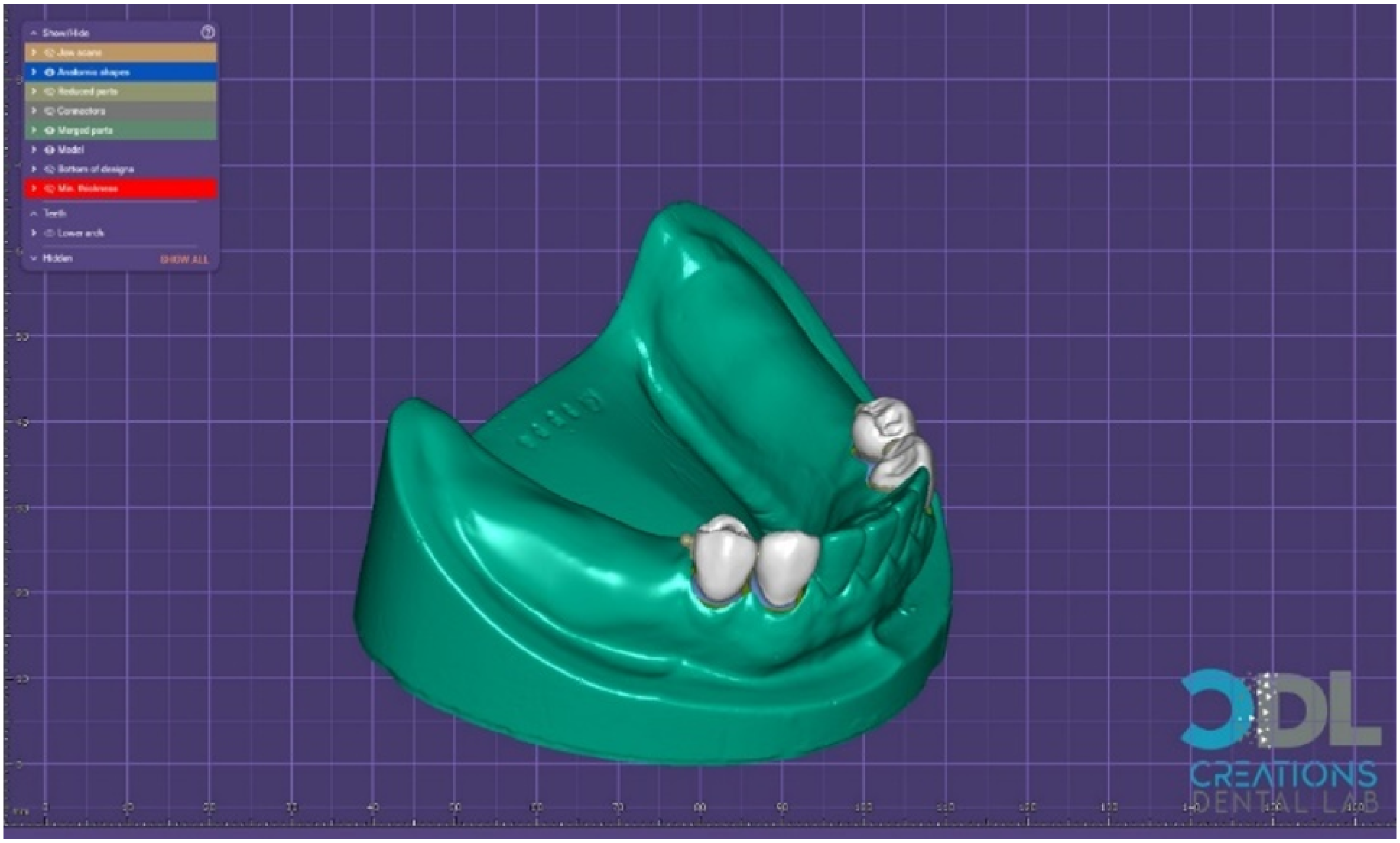

Figure 3

The virtual model with the designed full anatomical crowns and extra-coronal attachments.

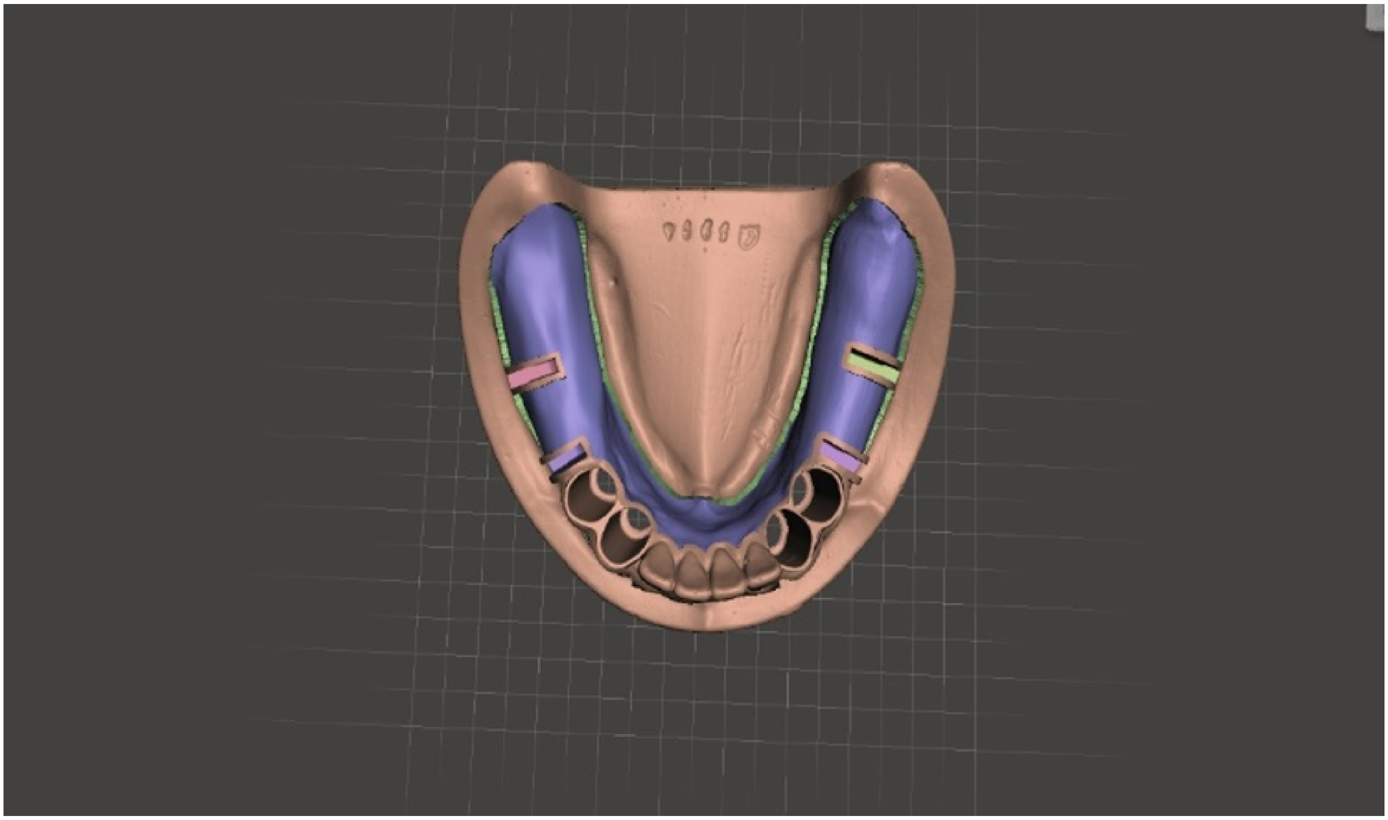

Figure 4

The virtual design of the model showing sockets of the prepared abutments, strain gauge slots and the cut-back for gingival simulation.

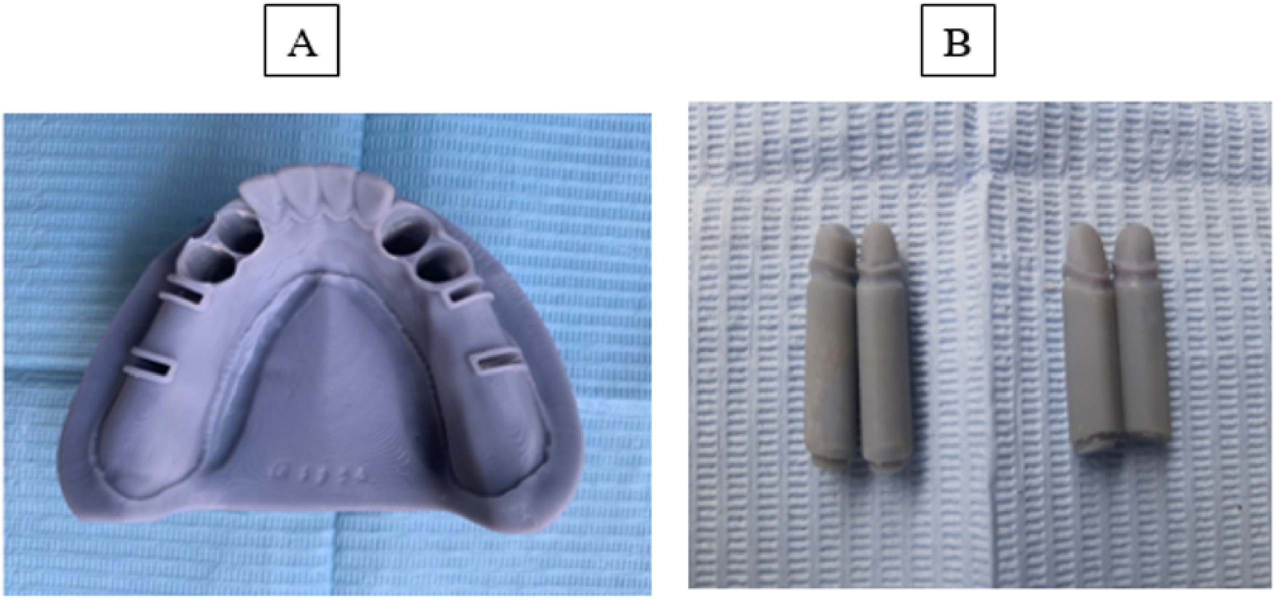

Figure 5

A-3D printed model with sockets of the abutments, prepared slots for the strain gauges and space created for soft tissue simulation, B-3D printed removable dies.

Figure 6

The 3D printed model with the mucosal simulation showing PEEK (BioHPP) crowns and the extra-coronal attachments.

Figure 7

The 3D printed model with the mucosal simulation showing zirconia crowns with the extra-coronal attachments.

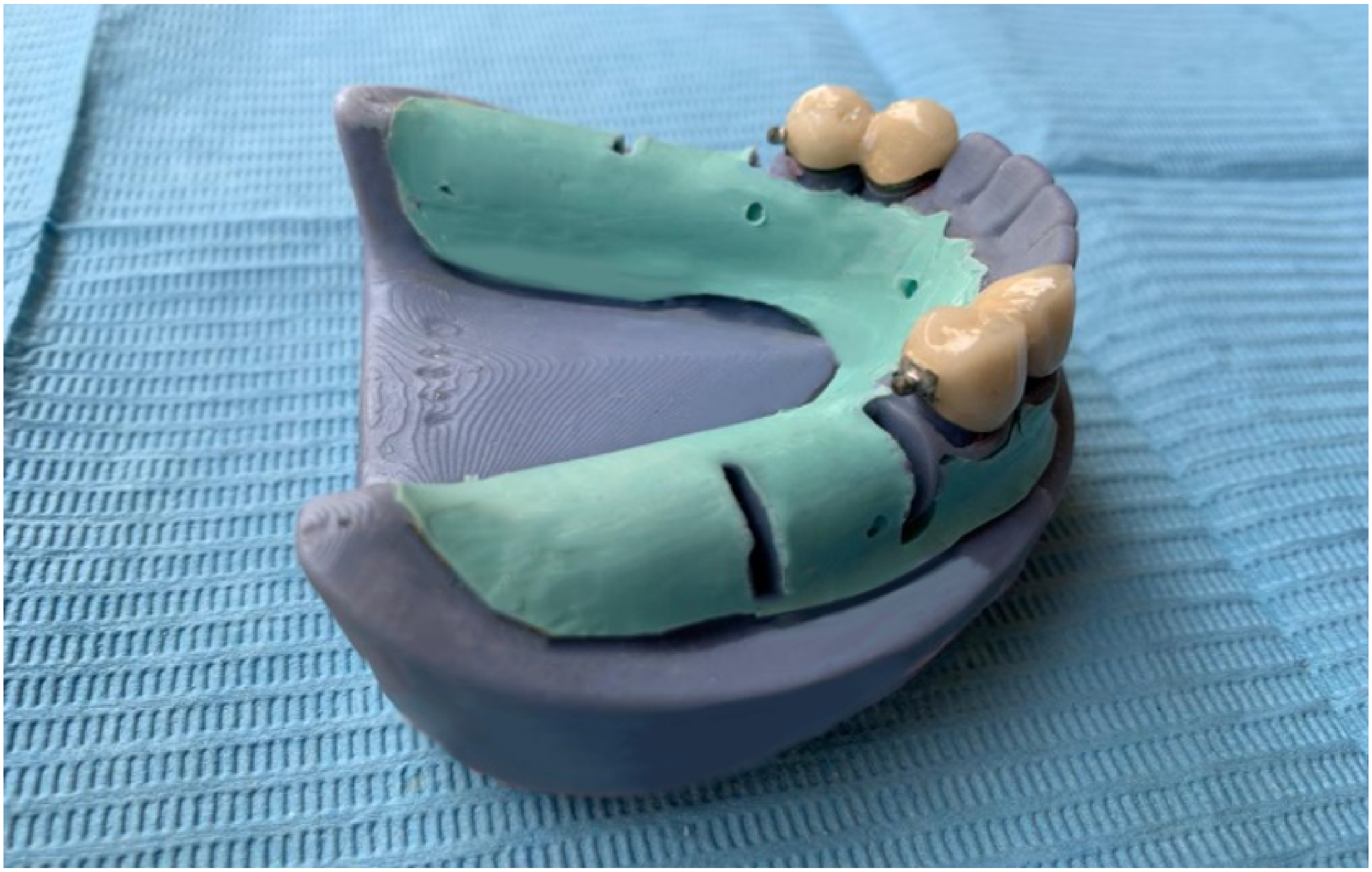

Figure 8

The 3D printed model with the mucosal simulation showing PFM crowns and the metallic extra-coronal attachment.

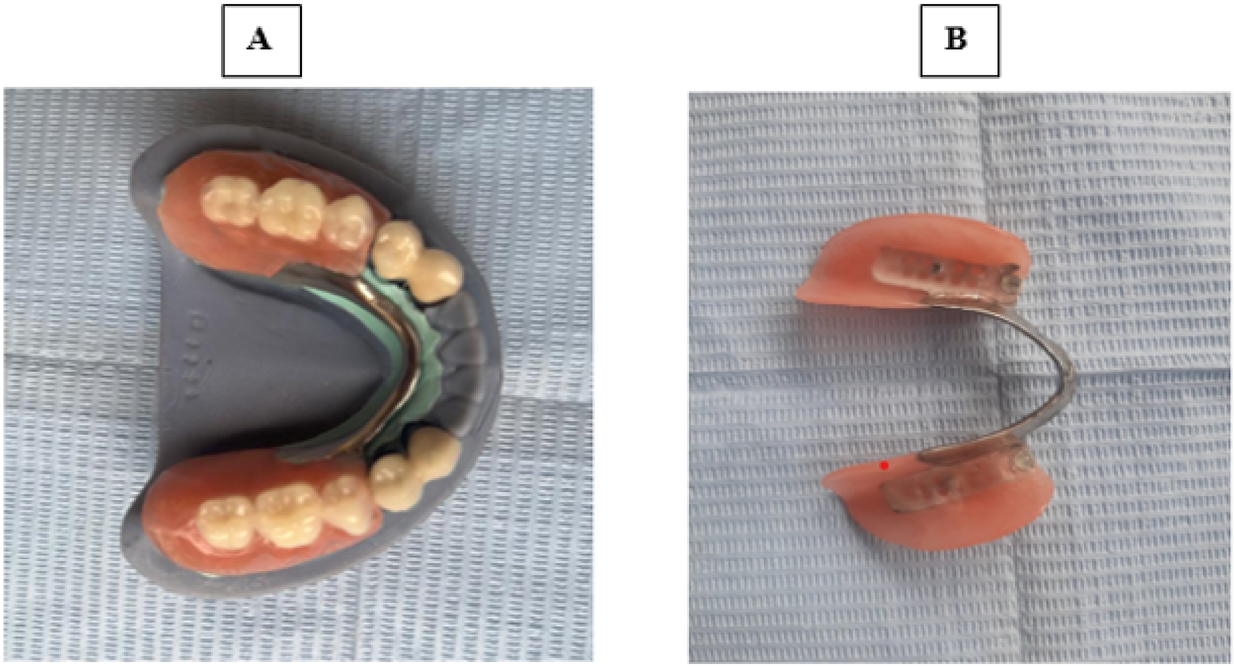

Figure 9

A-The extra-coronal attachment retained RPD, B-The fitting surface of the extra-coronal attachment RPD showing the nylon OT caps.

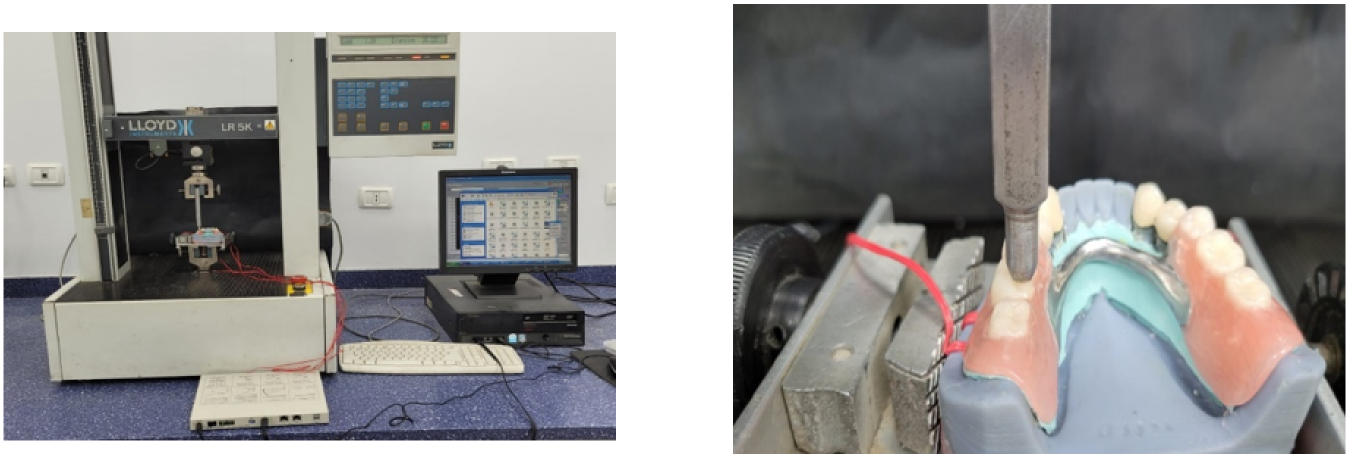

Figure 10

Unilateral load application on the RPD in the universal testing machine.

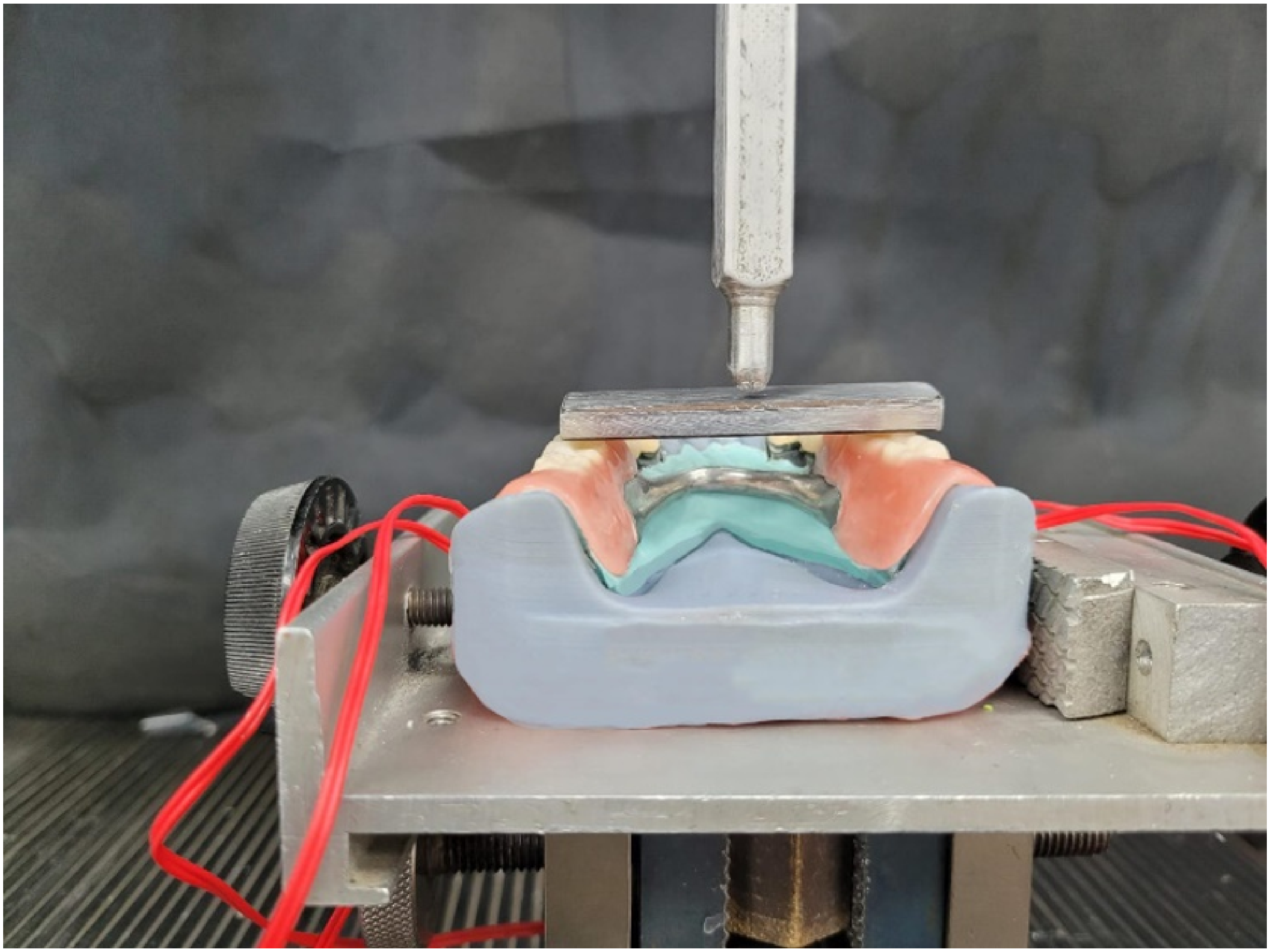

Figure 11

Bilateral load application on the RPD in the universal testing machine.

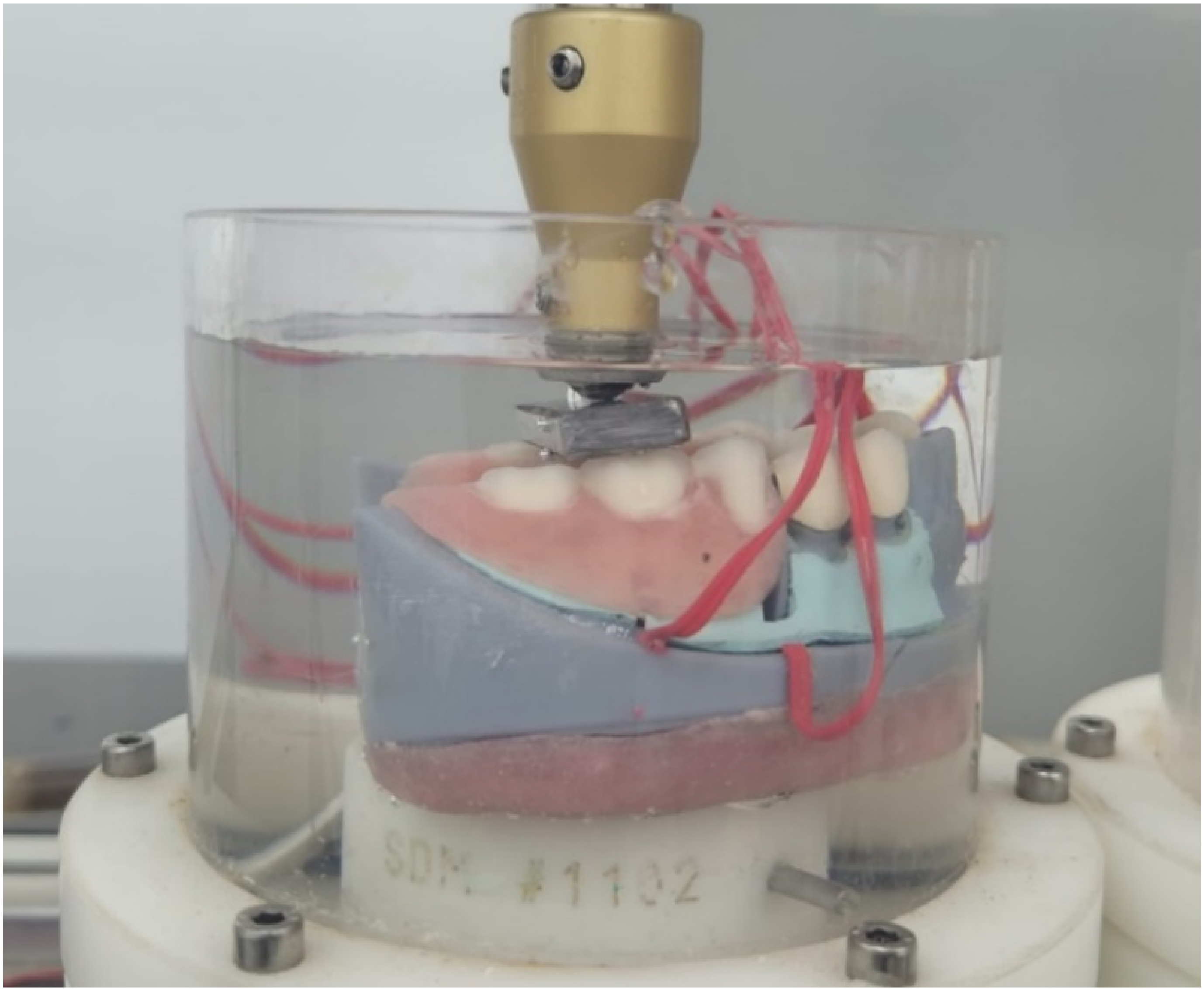

Figure 12

Load application on the partial denture in the chewing simulator.

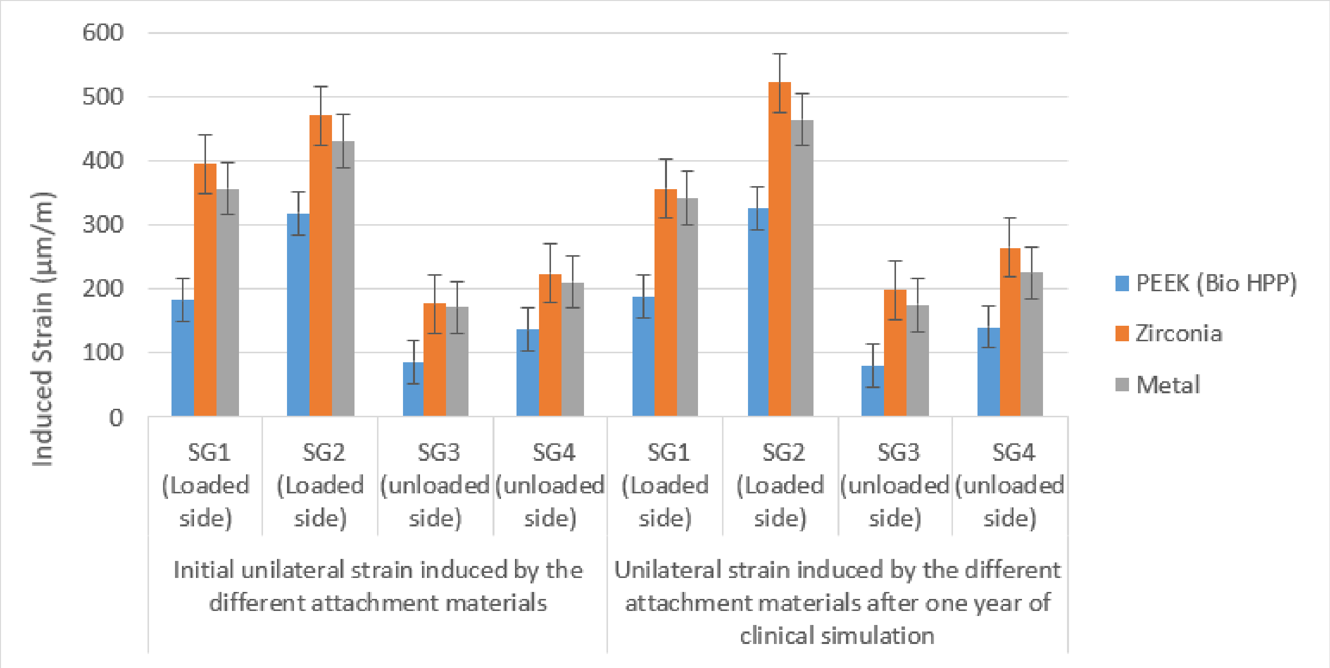

Figure 13

Bar chart showing the induced strain (um/m) distal to the abutments (SG1 & SG3) and the distal edentulous ridge (SG2 & SG4) for the three tested attachment materials during unilateral loading before and after 1 year of clinical simulation.

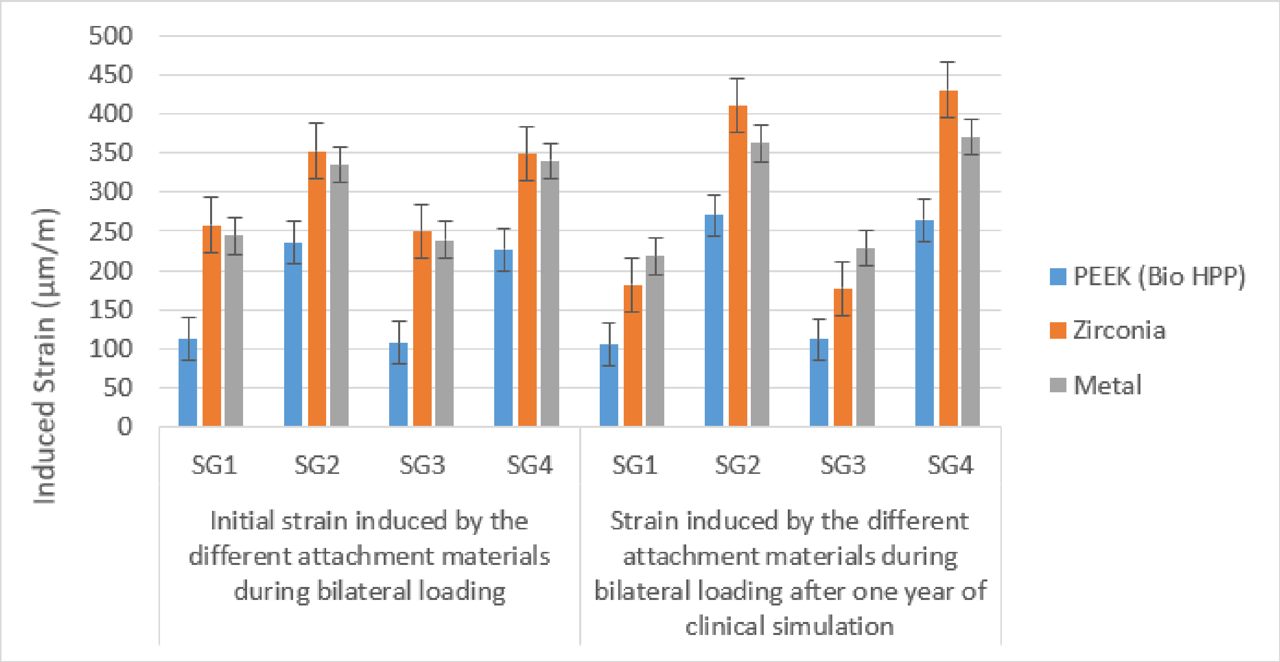

Figure 14

Bar chart showing the induced strain (um/m) distal to the abutments (SG1&SG3) and the distal edentulous ridge (SG2&SG4) for the three tested attachment materials during bilateral loading before and after 1 year of clinical simulation.