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STRAINS INDUCED BY ZIRCONIA AND METAL RESIN BONDED ATTACHMENTS VERSUS EXTRACORONAL ATTACHMENT WITH FULL VENEER RETAINER IN MAXILLARY DISTAL EXTENSION REMOVABLE PARTIAL DENTURES

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ABSTRACT

Aim of the study: The aim of this study was to assess the strains transferred by zirconia and metal resin-bonded attachments (RBAs) to the maxillary distal extension removable partial denture (RPD) supporting structures and compare them with the strains generated by the extracoronal attachment with full veneer retainers. **Materials and Methods:** Three identical partially edentulous models that were created with a 3D printing technology. The virtual models for the retainers and the three attachments were designed using digital software. Model (1): Zirconia resin-bonded attachment (ZRBA). Model (2): Metal resin-bonded attachment (MRBA). Model (3): Extracoronal attachment with full veneer metal ceramic retainer (ECFV). Using 3D printing technology, the wax patterns for the three types of attachments were printed, and the retainers were constructed and cemented on their models. This was followed by the fabrication of attachment-retained removable partial dentures on the three printed models: Each RPD was subjected to a compressive static load of 100N using a universal testing machine. Then the strain values were recorded. **Results:** On bilateral loading, there were significant differences in the recorded strains at the three strain gauge locations between RBAs and ECFV. At the SG-3 location, there was no significant difference between the strains generated by ZRBA and MRBA. During unilateral loading, the results revealed statistically significant differences between the three attachments at the loading and non-loading sides. **Conclusion:** With the limitations of this study, it can be concluded that, in distal extension maxillary RPD, there is no significant difference between the strains generated by zirconia and metal resin bonded attachments. While the extracoronal attachment with full veneer retainers applied less strains on RPD supporting structures than resin bonded attachments.

KEYWORDS: resin-bonded attachment, extracoronal attachment, strain gauges, in vitro, distal extension, removable partial denture.

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INTRODUCTION

Attachments that improve prosthesis retention, stability, aesthetics, and biomechanics can be utilized to connect distal extension removable partial dentures (RPDs) to abutment teeth. They directed stress to the cervical portion of the abutment in order to improve the appliances' force distribution. Because the force transferred to the tooth is more apically directed with attachments than with occlusal or incisal rests, the lever arm is reduced and torquing forces are minimized. [1]

Extracoronal attachments are usually attached to two splinted full-veneer retainers. To reduce the stress caused by such attachments, abutments should be splinted with full coverage retainers. Such full coverage restorations result in significant abutment reduction, which may jeopardize the pulp. Also, secondary caries is a common problem in these cases, and it usually causes the loss of abutment teeth. Furthermore, tooth fractures are the most prevalent cause of biological failure in extracoronal attachment-retained RPDs.[2-4]

Since 1980, resin-bonded attachments (RBAs) have been utilized to retain dental prostheses. Rochette developed the technique for resin-bonded restorations, which has been refined several times over the years. This treatment modality is now utilized to substitute missing anterior or posterior teeth with resin-bonded fixed partial dentures, as well as to retain RPDs with RBAs. [5,6]

RBAs-retained RPDs are a minimally invasive treatment option. Their key benefit is adequate attachment retention combined with minimal substance loss for abutment tooth preparation. Furthermore, they have supragingival margins, optimal stress distribution, and a more aesthetically pleasing appearance. If the abutment teeth adjacent to the edentulous regions are free of decay or fillings, they can be utilized. Clinical findings indicate that RBA-retained RPDs have a greater survival rate than those retained by attachments fixed to full coverage retainers. This could be because the adhesive preparation is minimally invasive and does not weaken the abutment tooth.[7,8]

The clinical workflows for RBAs and resin-bonded fixed partial dentures for RPDs are quite similar. Furthermore, comparable tooth preparation and bonding techniques for RBAs used for RDPs have been advised as for resin-bonded fixed partial dentures. The creation of parallel grooves in the enamel inside the contour of the resin-bonded retainer improves the binding between the retainer and the abutment. To avoid RBA displacement, two vertical retention grooves have been proposed to be prepared mesially and distally on the abutment tooth. In addition, the retention grooves act as a path for insertion during the bonding process. [9-11]

Several authors have reported on the use of metal-bonded components as rest seats, guide plates, attachments and retention undercuts.[12-16] Marinello and Scharer 1991[7] treated 34 patients with RBA-retained RPDs. In which etched metal castings with extracoronal attachments had been in service for 28 months. Thirty-one attachments remained in place, resulting in a 91% success rate. The authors of this clinical study found that RBAs were adequate to withstand the functional stresses of RPDs. Brudvik and Taylor 2000[17] described how resin-bonded metal components are used to fabricate definitive obturators for dentate maxillectomy patients.

Originally, RBAs were fabricated using metal alloys for the attachment male and the retainer. However, the need for sufficient bonding area, the greyish color of the metal, which may damage the aesthetics and translucency of the abutment tooth, as well as the need for vertical space requirements, are limitations that result in unsatisfactory survival rates.[6,7,12,15] Substantial advances in adhesive dentistry, positive experience with zirconia ceramic in all ceramic resin-bonded fixed partial dentures, and the present status of intraoral scanning and the introduction of computer-aided design (CAD) computer-aided manufacturing (CAM) might resurrect the adhesive attachments as a minimally invasive concept and a cost-effective treatment modality. After tooth preparation and intraoral scanning were done, CAD-CAM could be used to make male attachments from zirconia ceramic. [3,5,18]

Zirconia, sometimes known as "ceramic steel," has superior mechanical properties. It has a hardness of 1200 HV and a flexural strength of 900–1200 MPa. These values are far superior to all other prosthetic ceramic materials and comparable to metals utilized in metal-ceramic fixed prostheses. Zirconia technology has accelerated the development of metal-free dentistry over the last two decades, potentially providing high strength, biocompatibility, and aesthetic superiority. Zirconia is used in prosthetic restorations due to its exceptionally low thermal conductivity, increased corrosion resistance, chemical inertness, as well as its excellent flexural strength and hardness.[19,20]

Zirconia is used for veneers, primary telescopic crowns, full-and partial-coverage fixed restorations, inlays, onlays, post and core, implants, implant attachments, and abutments. In-vitro studies have shown that zirconia is quickly becoming one of the primary prosthetic materials used worldwide. For the retention of removable dental prostheses, there are currently several types of zirconia attachments available: an extracoronal attachment, a ball attachment for overdentures as a component of a zirconia post, and a bar attachment. [19-23]

Recent advancements in computer-aided design and manufacturing (CAD/CAM) have made it possible to use zirconia for many dental restorations. Zirconia milling with CAD/CAM- controlled milling equipment is used to fabricate zirconia restorations. The use of CAD/CAM technology provides the advantage of avoiding the various steps and faults associated with conventional casting techniques. This is extremely useful during attachment fabrication since an incorrect fit between the attachment components can result in attachment wear, loss of prosthesis retention, and adverse loading of the supporting structures. [24-25]

RBAs made of zirconia ceramic might be an effective alternative to metal RBAs. However, data supporting the use of zirconia ceramic RBAs is scarce in the literature. The retention of zirconia and metal RBAs before and after dynamic loading was studied by Jagodin et al 2019[5], who found that zirconia RBAs may be a clinical replacement for metal RBAs. To assess the influence of tooth preparation on zirconia RBA loading, Orujov et al 2022[3] conducted a finite element analysis and an in vitro study. They suggested using RBA constructed of zirconia ceramic if at least three tooth surfaces would be utilized for retention.

Strain gauge analysis is a technique for detecting microscopic deformation under varied loading conditions with little disturbance during testing. The circuit's function is to convert a resistance change to an electrical voltage, which can then be measured with great accuracy at the location in which the strain gauges are installed. Because of the tiny size and linearity of the resistance rate change, this method of stress analysis has provided a better understanding of stress transmission and distribution in different prosthetic appliances and different types of attachments in RPDs.[2,26,27]

To the authors' knowledge, there is no available literature to evaluate the strains developed by zirconia and metal RBAs. Hence, the aim of this study was to assess the strains transferred by zirconia and metal RBAs to the maxillary distal extension RPD supporting structures and compare them with the strains generated by the extracoronal attachment with full veneer retainers. The first null hypothesis was that there would be no difference in strains generated around maxillary distal extension RPD supporting structures by zirconia and metal RBAs. The second null hypothesis was that there would be no difference in strains generated by RBAs and extracoronal attachment with full veneer retainers.

MATERIALS AND METHODS:

This in-vitro study was conducted on three identical partially edentulous casts that were created with 3D printing technology. This was done via scanning an educational model (typodont model, plutus dental, Plutus World INC, China) simulating maxillary bilateral distal extension base with remaining anteriors, canines, and first premolars. The model consists of replaceable teeth to allow abutment preparation to receive the attachments used in this study. The study was carried out with three different attachments: a zirconia resin-bonded attachment (ZRBA), a metal resin-bonded attachment (MRBA), and an extracoronal attachment with full veneer metal ceramic retainer (ECFV). The following procedures were done:

Abutments preparation:

The canines and first premolars were reduced bilaterally using the drill press machine (Nouvag Headquarters, 9403 Goldach - Switzerland). A rubber base mold (3M Center Building 275-2SE-03, St. Paul, MN 55144-1000 USA) was used to verify the amount of reduction. On the educational model, a clear vacuum-formed stent was constructed. Abutments were prepared to receive full or partial coverage retainers depending on the type of attachment, as follows:

- **Abutments Preparation for ZRBA:** The maxillary canines and first premolars were prepared to receive two splinted, zirconia resin bonded partial coverage retainers. Their palatal surfaces had been reduced by 0.5 mm. The cervical finishing line was prepared as a chamfer. On each side of the proximal surfaces of the abutments, a groove with a length of 2.0 mm and a depth of 0.5 mm was prepared. Guiding planes were prepared on the distal surfaces of the first premolars. In both canines and first premolars, all axiogingival internal line angles were rounded off. [11, 28]
- **Preparation of abutments for MRBA:** Preparation of the maxillary canines and first premolars was done to receive two splinted, metal resin bonded partial coverage retainers. Their palatal surfaces had been reduced by 0.8 mm. The rest of the preparation was carried out in the same manner as in ZRBA.[6]
- **Abutments Preparation for ECFV:** The maxillary canines and first premolars were prepared for two splinted full veneer metal ceramic retainers with a 1.2 mm deep chamfer finishing line and occlusal and circumferential reduction.

Models deigning and printing

To get the Standard Tessellation Language (STL) file format, the educational model and prepared abutments were scanned using a 3D desktop scanner (DOF swing desktop scanner, Seoul, South Korea). The three virtual models for ZRBA, MRBA, and ECFV were designed using digital software (exocad GmbH; Darmstadt, Germany).

The prepared abutments were converted into removable dies with 0.2 mm of periodontal ligament space using 3D modelling tools. The saddle areas were depressed to a depth of 1.5 mm to make room for the tissue-simulating material. Three slots were created bilaterally in the virtual model to install the strain gauges. Two slots were cut, one buccal and one 1 mm distal to the first premolar abutment, parallel to its long axis. The third slot was created at the edentulous ridge's distal end. 3D modelling programs (Meshmixer 3.5, Autodesk, USA) and (Model Creator module of exocad GmbH; Darmstadt, Germany) were used to transform the prepared abutments into removable dies with 0.2 mm of periodontal ligament space. Also, both are used to create the gingival relined space, and the cutout slots with predetermined dimensions. ***(Fig. 1)***

The virtual models were transferred as STL files and 3D printed (3D printer © 2020 in3D Co.) using model resin (Pro shape dental cast resin). The printer produced the cast layer by layer, using UV light to polymerize the layers until the whole cast was made, starting at the bottom. ***(Fig. 2)*** Soft tissue-simulating material (Affinis, light body rubber base, Coltene Whaledent) was applied onto the printed models using the transparent vacuum-produced stent to replicate the mucosa and PDL, guided by the remaining teeth and the palate.

Retainers and attachments' design and construction

Using the STL files of the virtual models, the designing software (exocad GmbH; Darmstadt, Germany) was used to design the attachment patterns and the partial and full coverage retainers. The virtual model design had a partial coverage retainer thickness of 0.5 mm for ZRBA, a partial coverage retainer thickness of 0.8 mm for MRBA, and a full veneer retainer thickness of 1.2 for ECFV. To accommodate the bracing arms of RPDs, lingual ledges 1 mm above the gingival margin were constructed in the designs of the three virtual models. ***(Fig. 3 A, B)*** The extracoronal attachment used was an OT-strategy with a standard male of 1.8 mm (Rhein 83, Bologna, Italy). Using a software library (exocad GmbH, Darmstadt, Germany), the attachments for the three models (MRBA, ZRBA, and ECFV) were designed and attached to the retainers at the distal surface of the first premolars. Zirconia blocks (Zolid ceramill amanngirrbach, gmbh, Germany) were milled in a milling machine (Shera eco-mill 5x, Werkstoff-Technologie GmbH & Co. KG, Germany) and sintered to fabricate attachments and retainers for ZRBA. The patterns for MRBA and ECFV were 3D printed (3D printer © 2020 in3D Co.) utilizing wax (yamahachi, japan). The wax patterns were then conventionally invested and casted in nickel-chromium (Ecolloy CS,

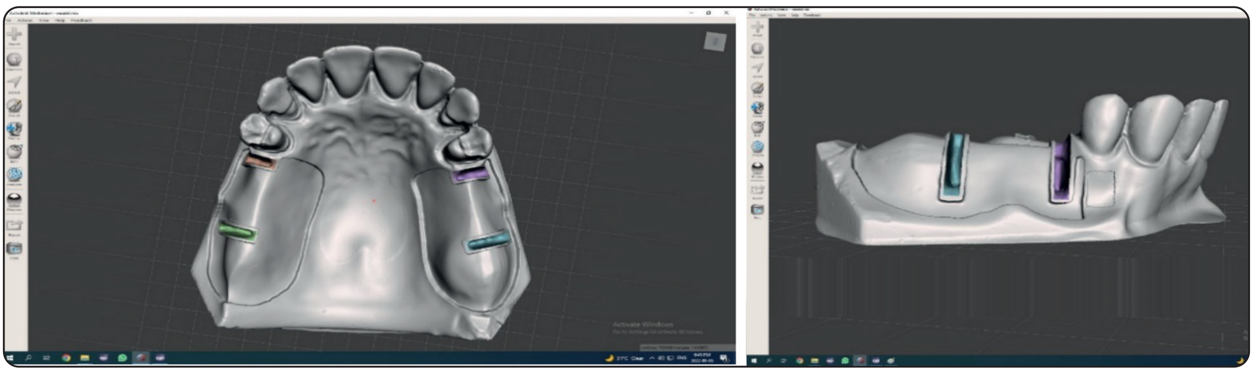

Fig. (1): The virtual model created by the designing software.

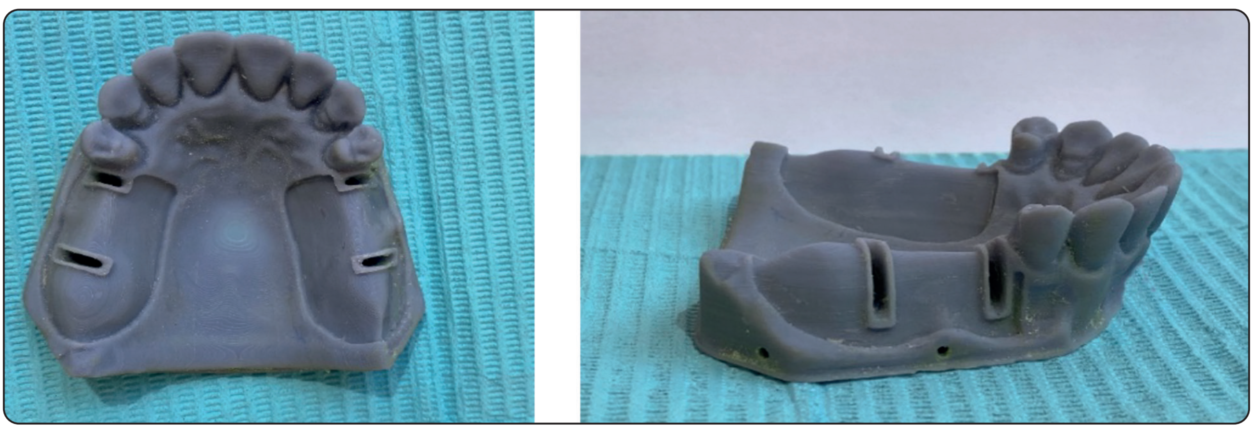

Fig. (2): The printed model with prepared abutments, strain gauges slots & the saddle areas depression for the soft tissue simulating material.

dentecon, Germany) and finished. The fit between the retainers and their abutment dies was checked, and all surfaces except the bonding surface were polished.

The bonding surfaces of the retainers were ultrasonically cleaned in distilled water for 10 minutes after being abraded with 70 mm Al_2O_3 airborne particles (0.2 MPa at 10 mm distance for 10 s). After cleaning the bonding surfaces of the dies with alcohol, a primer was applied (Panavia V5 Tooth Primer, Kuraray Noritake Dental Inc., Tokyo, Japan). According to the manufacturer's directions, the retainers were cemented to the models with resin cement (Panavia V5, Kuraray Noritake Dental Inc.) ***(Fig. 4 A, B, C).***

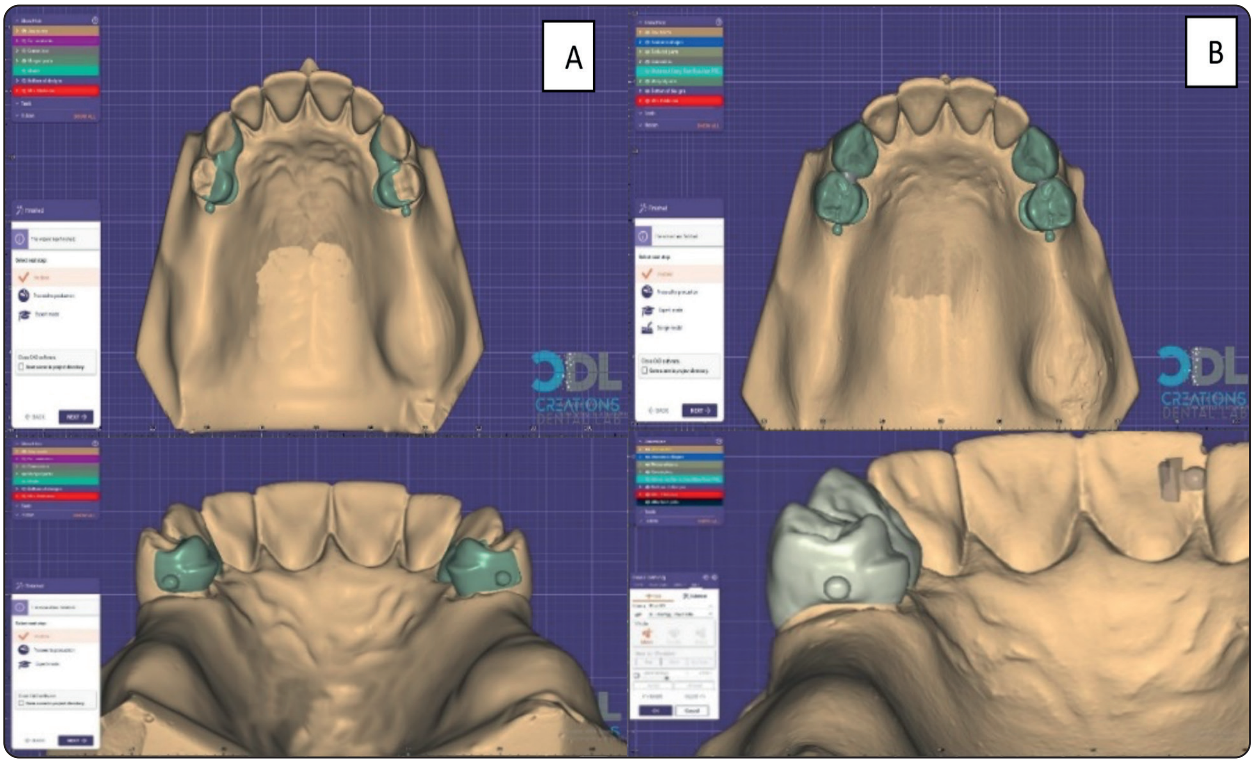

Fig. (3) (A): The virtual model of resin bonded attachment. (B): The virtual model of extracoronal attachment with full veneer retainer (ECFV).

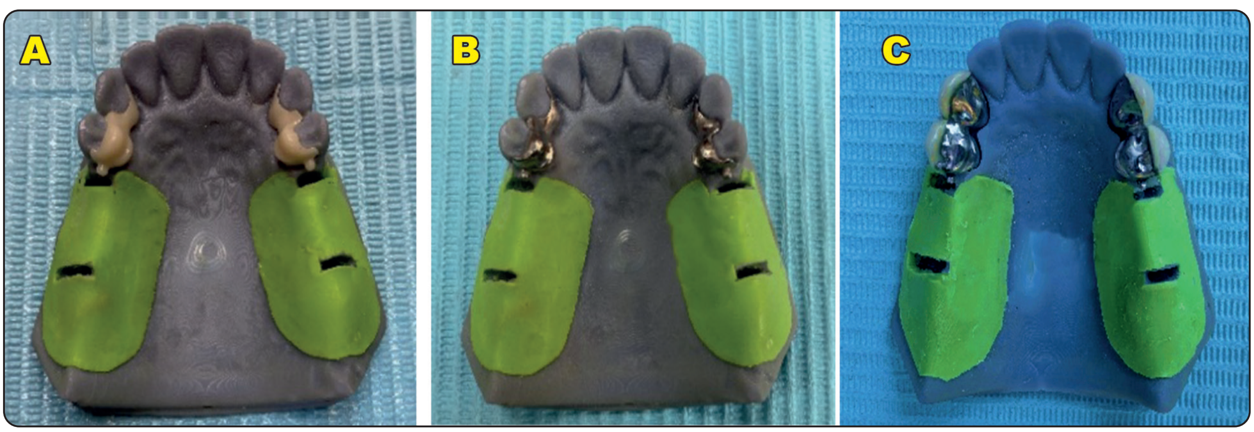

Fig. (4): The three printed models with the attachments and soft tissues simulating material: (A): Zirconia resin bonded attachment (ZRBA). (B): Metal resin bonded attachment (MRBA). (C): Extra coronal attachment with full coverage retainer (ECFV).

RPD design and construction:

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 (retainers and attachments) were used to design RPD for the three models with the same design and thickness. The RPD was designed as follows: combined denture bases, bracing arms on first premolars, and an antro-posterior palatal strap major connector. Three resin patterns of RPD frameworks were 3D printed using castable resin (NextDent B.V. Soesterberg, The Netherlands), then invested and casted into Co-Cr using the conventional technique.

The frameworks were seated to ensure a proper fit on their respective models. On one 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 three 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 create three identical RPDs. The attachment housings were picked up into the intaglio surfaces of the RPDs using a cold-cured acrylic resin (Acrostone, Egypt). ***(Fig. 5)***

Strain gauge installation and strain measurement

The strain gauge sensors (Strain gauges, Kyowa-Electronic Instruments Co, LTD, Tokyo, Japan.) used in this study had a gauge length of 1 mm, a resistance of 119.6 ± 0.4 Ω and a gauge factor of 2.13% ±1.0. They were attached to 100-cm-long lead cables. The strain gauges were placed at the buccal and 1 mm distal to the first premolar abutment, parallel to its long axis, and were labelled as SG-1 and SG-2, respectively. A third strain gauge was installed at the distal end of the edentulous ridge and was labelled as SG-3. They were oriented vertically and were cemented in their prepared slots with cyanoacrylate adhesive (©2016 Permabond LLC.) ***(Fig. 6)*** A dummy gauge was not needed for temperature compensation because the strain gauges used were temperature corrected for plastics. The gauge wires were inserted in specially prepared slots constructed in the model to prevent inadvertent dislodgement. To seal the slots created, self-cured acrylic resin was used. All of the wires were labelled to indicate the area to be measured.

For each model, a universal testing machine (Lloyd LR5K instrument, Fareham, Hampshire,

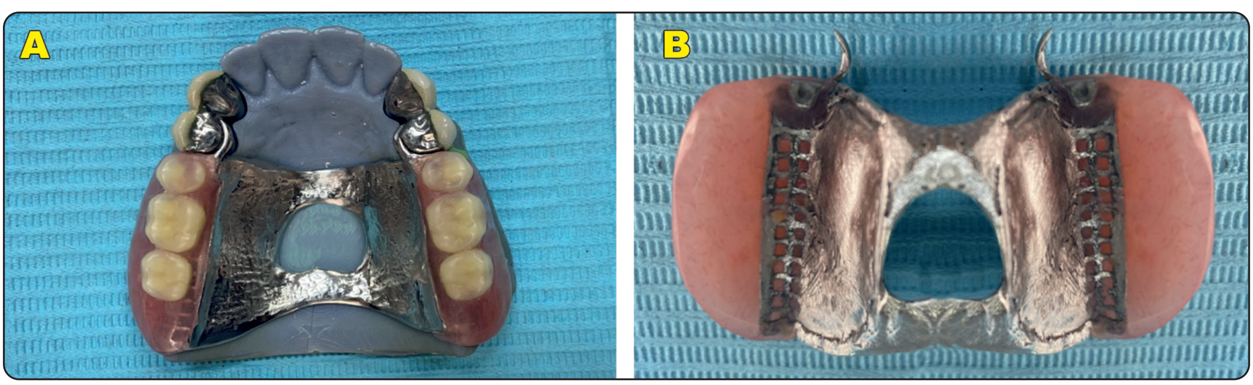

Fig. (5): (A) The finished attachment retained RPD on the model. (B): The fitting surface of RPD showing the attachment housings.

UK) was used to apply a static load starting from zero up to 100 N at an increasing constant load with a speed of 0.5 mm/min. The load was applied both unilaterally and bilaterally. For unilateral loading, an I–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 right side (loading side). A notch was cut with a diamond bur at the site of the load application to accept the tip of the loading applicator to avoid tip sliding and for reproducible measurements. Strains were recorded at the three sites (buccal and distal to the abutments and at the distal end of the ridge) on both the loading and non-loading sides. Bilateral loading was applied on the first molar on both sides using the T-shaped load applicator. Selective grinding with an articulating paper produced even contacts between the bar and the artificial teeth on both sides, enabling bilateral load application. The strains transmitted via the strain gauges were measured by a multichannel strain-meter (Model 8692, Tinsely precision instruments, Surrey, UK) using specialized software (Kyowa Electronic Instruments Co.,Ltd, Japan). ***(Fig. 7)*** Measurements were made for each model. All measurements were repeated five times with at least five minutes between each for recovery. The mean values of the recorded strains were statistically analyzed.

Fig. (6): Micro-strain gauges attached to the printed model with the channels' specification.

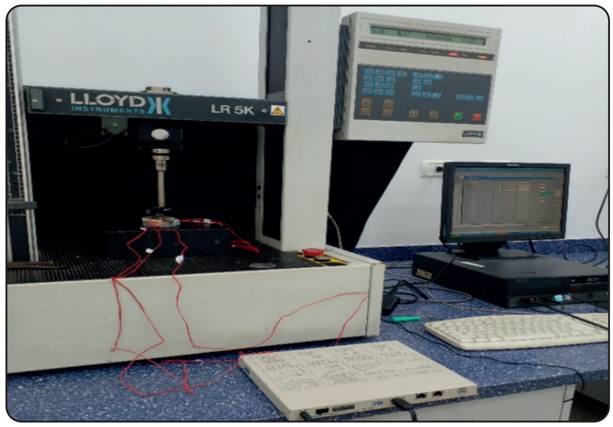

Fig. (7): Strain gauge measurement.

Statistical analysis:

The results were recorded and statistically analyzed. For data analysis, the SPSS statistical package for social science version 22 (SPSS Inc., Chicago, IL) was used. The Shapiro-Wilk test was performed to determine data distribution normality. The data had been parametric with a normal distribution. The mean ($\bar{X}$) and standard deviation (SD) were used to present numerical data. One-way ANOVA was used to compare between groups. A repeated measures ANOVA test was utilized to compare different strain values within the same group. For pairwise comparison, Tukey's post-hoc test was used. The significance level was set at $p < 0.05$.

RESULTS

The recorded micro-strain values around the abutment teeth and at the distal edentulous ridge during bilateral and unilateral loadings for the three attachments are shown in ***(Tab. 1)*** and ***(Tab. 2)***. The results of this study showed that when the three models were loaded bilaterally, the strains on the supporting structures were much lower than when they were loaded unilaterally.

During bilateral loading, the statistical analysis showed significant differences between strains recorded at the different strain gauge locations for the three models ($P<0.0001$). The highest strain was measured at SG-3, while SG-1 had the lowest strain.

TABLE (1): Micro-strains (Means ± standard deviation) recorded at the abutment and the distal edentulous ridge for the three attachments (ZRBA, MRBA, ECFV) during bilateral loading.

Model	SG-1		SG-2		SG-3		P-value
	X	SD	X	SD	X	SD	
ZRBA	209.6^{aA}	34.74	308.2^{aB}	15.17	428.4^{aC}	21.65	P<0.0001*
MRBA	235.8^{aA}	31.64	323.4^{aB}	18.94	467.4^{bC}	25.43	P<0.0001*
ECFV	100.4^{cA}	3.98	132.4^{cB}	10.40	164.8^{cC}	20.97	P<0.0001*
P-value	0.0169*		P<0.0001*		P<0.0001*		

X: Mean, SD: Standard deviation. ****Significant at P<0.05.***

Means superscripted with different small letters indicate statistically significant difference within the same column. Means superscripted with different capital letters indicate statistically significant difference within the same row.

TABLE (2): Micro-strains (Means ± standard deviation) recorded at the abutment and the distal edentulous ridge for the three attachments (ZRBA, MRBA, ECFV) during unilateral loading.

Model	Loaded side						Unloaded side						P-value
	SG-1		SG-2		SG-3		SG-1		SG-2		SG-3		
	X	SD	X	SD	X	SD	X	SD	X	SD	X	SD	
ZRBA	252.60^{aA}	28.89	347.20^{aA}	10.32	482.40^{aB}	7.89	138.80^{aD}	9.56	160.00^{aD}	6.07	216.20^{aG}	15.00	P<0.0001*
MRBA	277.6^{aA}	11.83	352.2^{aA}	23.32	523.2^{aB}	31.72	157.00^{aD}	3.85	180.80^{aD}	16.34	229.60^{aG}	11.25	P<0.0001*
ECFV	161.80^{bA}	20.04	202.80^{bA}	39.56	303.40^{bB}	39.17	83.00^{bD}	7.92	99.80^{bD}	6.68	119.20^{bG}	9.54	P<0.0001*
P-value	P<0.0001*		P<0.0001*		P<0.0001*		P<0.0001*		P<0.0001*		P<0.0001*		

X: Mean, SD: Standard deviation. ****Significant at P<0.05.***

Means superscripted with different small letters indicate statistically significant difference within the same column. Means superscripted with different capital letters indicate statistically significant difference within the same row.

On bilateral loading, the highest strain was displayed by MRBA, followed by ZRBA; the lowest strain was recorded by ECFV. There were significant differences in the recorded strains at the three strain gauge locations between each of ZRBA, MRBA, and ECFV (P<0.0001). Regarding the comparison between ZRBA and MRBA, there was a significant difference between the strains generated by them at SG-3 while there were insignificant differences between them at SG-1 and SG-2 locations.

When the three types of attachments were loaded unilaterally, statistically significant differences were found between the loaded and unloaded sides, as well as between the abutment and the ridge on each loaded and unloaded side. In a comparison between the three models during unilateral loading, the results revealed statistically significant differences between the recorded strains at the three strain gauge locations between each of ZRBA, MRBA, and ECFV (P<0.0001) at the loading and non-loading sides. While insignificant differences were found between the strains induced by ZRBA and MRBA at the three strain gauge locations at the loaded and unloaded side.

On the loaded side, the highest strains were recorded in MRBA at SG-1, SG-2, and SG-3 respectively, (277.60 µm/m ± 11.83), (352.20 µm/m ± 23.32), and (523.20 µm/m ± 31.72). This was followed by ZRBA (252.60 µm/m ± 28.89), (347.20 µm/m ± 10.32) and (482.40 µm/m ± 7.89) at the SG-1, SG-2, and SG-3, respectively. Then ECFV (161.80 µm/m ± 20.04), (202.80 µm/m ± 39.56) (303.40 µm/m ± 39.17) at SG-1, SG-2, and SG-3, respectively. While on the unloaded side, the lowest strains were (83.00 µm/m ± 7.92), (99.80 µm/m ± 6.68), (119.20 µm/m ± 9.54) for ECFV, (138.80 µm/m ± 9.56), (160.00 µm/m ± 6.07), (216.20 µm/m ± 15.00) for ZRBA, and (157.00 µm/m ± 3.85), (180.80 µm/m ± 16.34), (229.60 µm/m ± 11.25) for MRBA at SG-1, SG-2, and SG-3, respectively.

DISCUSSION

Distal extension RPDs encounter a variety of design challenges. One of them is the problem of disparity of support because of the lack of a distal abutment. Under occlusal load, the distal extension base rotates in a tissue-ward direction. This rotation tendency is due to a mismatch in the viscoelastic nature of the mucosa and the teeth. To disperse occlusal stresses between abutment teeth and the remaining ridge, numerous treatment options were proposed. For distal extension RPDs with only a limited degree of distal rotation, extracoronal attachments have been suggested.[29,30]

Extracoronal attachments have the advantages of reducing torque on abutments, distributing stresses between abutments and the edentulous ridge, and promoting RPD retention by eliminating visible clasps. However, splinting of the abutment teeth is required to lessen the pressure generated by this attachment. So, a significant amount of abutment reduction is necessary for their splinting by full-coverage retainers.[2,31]

With the advent of minimally invasive dentistry, several authors have advocated the use of RBA as a method for improving denture retention while preserving tooth structure. Reviewing the literature revealed studies on the usage of RBAs as RPD retainers. However, those studies have mainly focused on the clinical procedures for using this type of attachment. To the authors' knowledge, no research has been carried out to evaluate the stress transferred from RBAs to the removable partial denture supporting structures. So, the goal of this study was to assess the strains transferred by zirconia and metal RBAs to the distal extension RPD supporting structures, as well as to compare them with those created by extracoronal attachment with complete veneer retainers. [5,11,15]

This study was conducted in-vitro in order to have more control over the variables and to allow for better assessment of the changes that occurred. It has been proven that in-vitro studies are more frequently used in the stress analysis of oral structures than in-vivo research because the histological structures of periodontal tissues and bone consistency differ between patients. So, in-vitro studies can be repeated under the same conditions. Also, it gives reliable comparison data while taking into account differences in the tissues that cover the ridge and the shape and quality of the ridge that supports it.[31-33]

In the current study, strain gauge analysis was used to analyze strains because it allows quantitative examination of strain around the abutment and edentulous ridge supporting a distal extension RPD. This approach is one of the most often used ways for measuring stress and deformation and may overcome many of the drawbacks of other methods because of its compact size, linearity, and lower interference while testing.[34,35]

The test models for this study were created using CAD/CAM and 3D printing technology. This is supported by the high precision of the 3D-designing and printing techniques, which aim to standardize the conditions applied in the three tested attachments. The accuracy of 3D-printed models may be linked to the fact that they have little or no internal stresses owing to the layer-by-layer method of production of the cast.[23-25]

Three strain gauges were placed on each side, two around each second premolar abutment on the buccal and distal sides, and the third one was on the edentulous ridge. This is in accordance with other studies that advocated a similar placement of strain gauges to monitor strains around abutments. With this setup, strains were measured precisely and conclusively over a wide area of supporting structures and accurately monitored the effect of applied load. To create a realistic stress distribution during loading, soft tissue-simulating material was injected into the periodontal ligament space and applied to the edentulous ridge.[2,36,37]

When using extracoronal attachment for distal extension RPDs, fixed splinting of neighboring abutment teeth is critical. To help with force distribution, a minimum of two teeth on each side should be splinted with either full or partial veneer retainers. In this study, the canine and first premolars on each side were splinted to aid in stress distribution. This was implemented in the three attachment models, ZRBA, MRBA, and ECFV. Fixed splinting of abutment teeth for attachment-retained RPD has been proposed as providing enhanced resistance solely to antero-posterior stresses, while forces acting in a buccolingual direction can be resisted by cross-arch stabilization by RPD anchored on both sides of the arch.[2]

In our study, both metal and zirconia RBAs were tested as retainers for distal extension RPD, as zirconia has been used as an aesthetic alternative for metal in resin-bonded dentures. CAD/CAM designing and printing were used in our study for standardization and accuracy of the results. [3,11] The retainer thickness of the zirconia RBA was 0.5mm, while the metal RBA retainer was 0.7mm thick. This was similar to the preparation of zirconia and metal resin-bonded fixed partial dentures. RBAs have been discovered to be resistant to debonding when grooves are prepared on the abutment teeth and the bonding surface area is increased.[3,11,28] A ledge was prepared on the retainers to accommodate RPD bracing arms. It has been reported that the use of bracing arms may lower the stresses falling on the attachment and may improve the bracing action.[2,38]

The results obtained from this study showed that the strains transferred to the supporting structures during bilateral loading in the three models were significantly less than during unilateral loading. This finding could be attributed to the wide distribution of forces over a wide area during bilateral loading. Stresses applied to any portion of RPD are distributed over the supporting area, the abutment teeth, and the underlying bone due to the rigidity of the major connector. While under unilateral loading, the stresses were concentrated at the loaded side abutment and ridge as the rotational movement of the prosthesis concentrated the stresses at the loaded abutment and ridge.[39,40]

There were no available similar studies that compared the strain transferred by ZRBA, MRBA, and ECFV in distal extension RBDs. So, we couldn't compare our results to other previous stress analysis findings. The first null hypothesis was accepted as there were no significant differences between ZRBA and MRBA regarding the strains developed in the abutments and edentulous ridge supporting RPDs. This could be attributed to the very close material properties of metal and zirconia. Some authors have advocated that the type of prosthetic material used has little effect on the stress transmitted to the bone.[41-44]

The findings of this study revealed that ZRBA exhibited insignificantly lower strains on RPD supporting structures than MRBA. This might be consistent with a clinical study comparing zirconia and metal extracoronal attachments in removable partial dentures that found insignificantly reduced residual ridge bone loss with zirconia than that of metal attachments, which is an indication that the zirconia attachment transferred less stress to the supporting structures.[45] Also, Menani et al.[46] found that using ceramic prostheses reduced the magnitude of stress transmission to the bone. When considering the transfer of stress, the use of ceramic materials would be valuable for implant survival. This proved the current study's findings that the force transfer of ZRBA was lower than MRBA.

Zirconia is less likely to be distorted due to its high rigidity. This finding suggested that zirconia may be more valuable for resin-bonded attachments than metal. These results are in accordance with Jagodin et al 2019[5] who found that the zirconia resin-bonded fixed partial dentures were less likely to be distorted than the metal. Moreover, the strain of zirconia resin-bonded fixed partial dentures showed no difference from the metal, even if the retainer thickness was changed. [46]

The second null hypothesis was rejected as the unilateral and bilateral loading conditions revealed significant differences between RBAs and ECFV on the average strains transferred to RPD supporting structures. This could be explained by the fact that full coverage retainers distribute stresses across a larger tooth crown area, transferring less strain to the abutment. [47-49]

Concerning unilateral loading, significantly higher strain values were recorded on the loaded side when compared with the unloaded side for the three models of the study. This was consistent with other stress-strain analysis studies, in which stresses tend to be attenuated on the contralateral side of the load application, resulting in significant differences between both sides. This research found that the abutment root surface of the loaded side of RPD was significantly subjected to more strain compared to that of the unloaded side. This result is explained that, unilateral loading is responsible for greater stress transmitted to the loaded side compared to unloaded side as result of rotation of the prosthesis "toward the loaded side" along the center of the dental arch. [36,50]

The recorded strains were greater for the distal extension strain gauges than for the buccal and distal strain gauges. This might be due to the proximity of the leverage generated by the attachment ball on the distal side, which concentrates the stresses on it. Also, this might be explained by the denture rotation toward the tissue, which increases the ridge loading conditions.[51]

There are several limitations to this study. This study solely looked at axial stress and did not take into account the complexities of masticatory loads. Furthermore, the use of static loads in the evaluation of RPDs causes two major problems. Because it gives information that is accurate only for the precise locations of measurement, determining whether the selected points are the appropriate ones for evaluating the RPD becomes problematic. Also, replicating the chewing cycle is difficult.

CONCLUSION

With the limitations of this study, it can be concluded that, in distal extension maxillary RPD, there is no significant difference between the strains generated by zirconia and metal resin bonded attachments. While the extracoronal attachment with full veneer retainers applied less strains on RPD supporting structures than resin bonded attachments.

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