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Effect of CAD/CAM zirconia versus cast metal attachment on stresses induced in Kennedy class I cases (Strain gauge analysis)

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Background: The removable partial denture (RPD) continues to be an essential prosthetic consideration especially when edentulous ridges posterior to a patient's remaining teeth are to be restored. Precision attachments are used as extra-coronal retainers which are characterized by considerable retention improvement. In the current study, we aim to assess strains develop in supporting structures of two study groups resembling Kennedy class I partially edentulous cases which are rehabilitated with Co-Cr cast metal and CAD/CAM milled zirconia successively.
Aim: To evaluate the effect of two different extra-coronal attachments, (Co-Cr cast metal and CAD/CAM milled zirconia) on stresses induced in supporting structure in Kennedy class I cases.
Materials and Methods: This in vitro study was conducted on partially edentulous Kennedy class I cases. Two materials used in the construction of extra-coronal attachment retaining removable partial dentures were investigated; cast Co-Cr and CAD/CAM milled zirconia. The stresses induced were evaluated using the electric strain gauge analysis technique.
Results: evaluating the strains developed in both groups showed a statistically significant increase in stresses induced in the group rehabilitated with Co-Cr cast metal attachments compared to the group of CAD/CAM milled zirconia on the loaded side and a statistically insignificant difference in the unloaded side.
Conclusion: CAD/CAM milled zirconia and Co-Cr cast metal attachments showed a different distribution of forces as the zirconia attachment transmits fewer stresses to the loaded and unloaded sides compared to the metal attachment.

Keywords: Removable partial denture, Extra-coronal attachments, CAD/CAM zirconia

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INTRODUCTION

Posterior distal extension partial denture presents several design challenges, especially the equitable distribution of forces to maintain remaining alveolar ridges and teeth in an optimal state of health and to provide the patient with improved comfort and function [(1)]. The selection of retainers suitable for distal extension RPDs and the concept of connecting the denture with the remaining teeth are key factors in the preservation of abutment teeth and the long-term success of RPDs [(2)].

Extracoronal attachments improve the retention, support, stability, and esthetics of the denture and transfer forces along the long axis of the abutments [(3)]. An ideal all-ceramic restoration that conforms well and demonstrates improved biocompatibility, strength, fit, and esthetics has always been desirable in clinical dentistry. On the other hand, the inherent brittleness, low flexural strength, and fracture toughness of conventional glass and alumina ceramics have been the main obstacles to the extensive use of all-ceramic restorations. The recent introduction of Zirconia-based ceramics as a restorative dental material has generated considerable interest in the dental community, which has been expressed with wide industrial, clinical, and research activity, especially with the introduction of computer-aided design (CAD)/computer-aided manufacturing (CAM) systems [(4)].

Although numerous in-vivo and in-vitro studies have been conducted on the influence of different attachments on the abutment supporting structures, however, there is little information about the effect of CAD/CAM milled zirconia extracoronal attachment retained removable partial dentures on stresses induced on the abutments and retention of bilateral distal extension cases.

This study aims to evaluate the effect of two different extracoronal attachments, (Casted Co-Cr and CAD/CAM milled Zirconia) on stresses induced in supporting structure in Kennedy Class I cases.

MATERIALS AND METHODS

This in vitro study was conducted on a partially edentulous mandibular arch representing Kennedy Class I (Bilateral free end saddle) restored by extracoronal attachment retained removable partial denture. Two materials were used thus two groups were classified: **Group (I):** Casted Co-Cr Extracoronal attachments Retaining Removable Partial Denture. **Group (II):** CAD/CAM milled Zirconia attachments Retaining Removable Partial Denture.

The study was performed on 3D experimental models simulating symmetrical Kennedy Class I with the first premolars being the last standing abutments to evaluate strain induced on the abutment supporting structures.

1. Model construction

An educational model representing the Kennedy class I case, with the first premolars being the last standing abutments was constructed. The model was designed using the Meshmixer program (Model Creator- Exocad GMBH, Germany).with detachable dies for bilateral last two abutments with an apical stop. On the program, the last two abutments on each side were prepared with a deep chamfer finish line of 1 mm and a tapered wall of 3 to 4 degrees to achieve retention to the crowns that will be constructed. A cut back was done on the ridges to create a space for mucosa simulation with 2mm thickness, a groove distally to the first premolar abutments was created to install the strain gauges, and periodontal space about 0.25mm around the root of the abutments also created to simulate the periodontal membrane space (fig.1). The design was converted to an STL file for model 3D printing from curable resin (NextDent

Model, Nextdent B.V., Netherlands) by an additive manufacturing device using a digital light processing technique (Dent 2 Mogassam, Mogassam Co., Delaware, USA)(fig.2)

A virtual wax build-up was done on the 3D model over the designed space for mucosa simulation then a template was designated and printed as well as the model. Then the template is used to create a silicon layer over the acrylic model to simulate the effect of the mucosa. An adhesive for bonding mucosa gingival was painted over the model. Mucosa gingival mask (GINGISIL, soft Endhärte Shore a 45, dent-e-con e.k, Germany.) was injected around roots of abutments and into the stent; it was pressed over the model to simulate mucosa and periodontal membrane space.

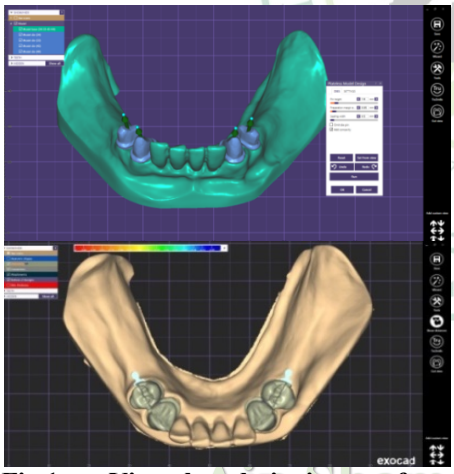

Fig.1: Virtual designing of the experimental models on the software (Mishmixer)

Fig. 2: 3D printed educational cast representing Kennedy class I

Crowns and attachments construction:

The experimental models were scanned and STL files were generated to use CAD/CAM technology for designing and milling crowns and attachments (Coritec 350i series, imes-icore® GmbH, Germany). The design chosen for the extracoronal attachment in this study was a vertical stud (key and keyhole) from the Bredent digital library.

For the construction of group I attachments, the design was picked up on software, STL file generated and used for CAD/CAM milling of the wax pattern followed by conventional casting for metal attachments(fig.3).

For group II, the attachment of choice was picked up on software, zirconia (Ceramill Zirconia – Amann Girrbach AG, Koblach, Austria) crowns and attachments were milled (using a five-axis milling machine) (fig.4)

Fig. 3: Computer-assisted designed and milled wax pattern and finished casted crowns and attachments

Fig. 4: CAD/CAM designed and milled crowns and attachments

Construction of metal framework and final denture:

A metal framework was waxed and cast then finished and polished. The framework was tried for fitting and the denture was flasked for each experimental model, wax was eliminated, and the heat-cured acrylic resin was packed and cured then finished and polished following conventional techniques (Vertex regular acrylic denture base, vertex-dental, Netherlands). (fig.5)

Fig. 5: Finished removable partial denture

Stress analysis

The strain gauges used in this study had a length of 1 mm, a width of 2.4mm, and nominal resistance of 120 Ohm (Strain gauges, kyowa, Japan). The strain gauges were installed in their grooves at the distal aspect of teeth paralleling the long axis of their roots. It was fixed in position on the acrylic model by a delicate layer of Cyano Acrylate-based adhesive cement.

The Universal testing machine (Universal Testing Machine, LLOYD, U.K.) was used for applying vertical static unilateral load ranging between 0-100 Newton on the loading point between the second premolar and first molar. A two-channel strain meter was used to assess the strains induced by the applied load. Chisel shaped load applicator was used to apply load unilaterally on the right side to represent the loaded side between the second premolar and first molar. The micro strains of each strain gauge were recorded to measure the strains induced at the loaded and unloaded sides after load application. Once the load was completely applied, the microstrain readings were transferred to microstrain units. Data were tabulated and statistically analyzed. (fig.6)

Fig. 6: Universal testing machine, point of load application between the second premolar and first molar (loaded side) (Group I)

RESULTS

Recorded data were analyzed using the statistical package for social sciences, version 23.0 (SPSS Inc., Chicago, Illinois, USA). The quantitative data were presented as mean± standard deviation and ranges. Student T-test was used to compare between two groups. A probability level of $P \leq 0.05$ was considered statistically significant.

Stress analysis:

Microstrain values induced to the abutments during unilateral loading for each group are shown in (Table 1). Data are presented as mean and standard deviation (SD) values. Regarding the loaded side, the mean value of stress analysis "microstrain" was found to be of higher value for group I (645.50±58.45) than for group II (495.00±14.03). Statistical analysis of the data revealed a significant difference between groups with a p-value ($p<0.05$). Regarding the unloaded side, the mean value of stress analysis "microstrain" was found to be of lower value for group II (176.50±29.73) than for group I (218.50±47.79). Statistical analysis of the data revealed an insignificant difference between groups with a p-value ($p>0.05$).

Table (1): Mean, Standard deviation (SD), and Student t-test for the value of stress analysis "microstrain" for the group (I) and group (II) during unilateral loading.

Stress analysis "microstrain"	Group I		Group II		t-test	
	Mean	±SD	Mean	±SD	*T*	p-value
Loaded side	645.50	58.45	495.50	14.03	7.92	<0.05
Unloaded side	218.5	47.79	176.50	29.73	3.21	>0.05

DISCUSSION

A wide variety of designs of clasps, attachments, materials, and production techniques have been introduced to provide esthetically dental prostheses that control torquing forces on the abutment and preserve the abutment teeth and supporting structures [3]. Kennedy class I was selected as an issue for the study as this condition is the most common case among partially edentulous patients, with 20% and 50% incidence in the maxilla and mandible, respectively. [5]. There is a difference in compressibility between teeth and tissues so removable partial denture is liable to move due to functional loads such as those created by mastication [5, 6].

Extracoronal attachment was proposed as the line of treatment as the extra-coronal attachments provide superior retention and aesthetics over clasps. [7] Extra-coronal attachments do not require preparation within the contour of natural teeth which may affect the health of the pulp also these attachments preclude the contour of the crown which may cause plaque accumulation and pocket formation. [3]

Cobalt chromium alloy a conventional metal used in prosthetic restorations has excellent physical properties. For example, they exhibit the highest modulus of any alloy type used for cast restorations. However, the elastic modulus of Co-Cr alloy (200 GPa) is almost double the titanium's modulus (110 GPa), Therefore, the higher stress concentration was calculated in the Co-Cr. [8]

The use of computer-aided design and manufacturing (CAD/CAM) is an alternative to the conventional casting technique. Also, CAD/CAM technology precludes human factor variations and improves quality control in dental laboratories. [9].

The current study took place in vitro rather than in vivo as the direct measurement of strains in the intraoral structure results in difficulties in standardization and reproducibility of the results, added to the presence of saliva and the possibility of strain gauge movement. There are wide variations from one patient to another and different parts within the same oral cavity [11]. Utilizing an educational model precludes the effect of the complex geometry and physiology of oral structures on the produced results of our study. The mandibular model was used in this study instead of an upper maxillary model because most of the challenges are reported in such arches due to the limited denture-bearing area and the nature of the mucosa and bony structure that support the denture base [10, 11]. The model used in this study was fabricated utilizing 3D printing technology. Rapid prototyping technology has gained enormous interest among practitioners because it greatly facilitates the realization of three-dimensional objects and the speed of production along with the high accuracy of the produced items. [11]

Bergman et al. [12] suggested that at least two abutment teeth should be splinted when extracoronal attachment prostheses are used, to improve stress patterns. On this basis, this study utilized two abutments on each side of the arch.

Scanning was done digitally, to the last two abutments which were prepared on the program to receive two crowns and an attachment chosen from the digital library of the Exocad program, a vertical stud attachment from Bredent, to benefit from the simple and reproducible morphology of this form in decreasing the liability of blocks fracture during milling procedure. Studying stress analysis, the electric resistant strain gauge technique was done to compare the stress patterns produced by variable materials restoring Kennedy class I. The strain gauge system was found to be a stable and accurate system. The strain gauge assesses strains induced into a loaded structure by referring to the change in resistance of an electric wire in the strain record [15].

The strain gauge analysis technique was chosen in this study to evaluate the strain on the supporting structures. It is considered highly accurate as it can recognize very slight strains [14]. To reach an accurate result and to standardize the level of sensitivity of the strain gauge, the decided sites for strain gauge mounting were made flat not curved, and distal to last abutments by 1mm. Strain gauge meters were adhered to their planned positions with a thin layer of Cyano-Acrylate base adhesive to standardize their location. Moreover, all the strain gauges used had the exact dimensions, resistance, and gauge factor. [15]

The maximum load applied was about 100 N to correspond with the average mastication forces required for the majority of food types. Fifteen minutes were given to the strain gauges to be in zero balance and to allow complete rebound of the resilient structures before starting the next reading [13].

The mean value of stress analysis "microstrain" was found to be of higher value for group I than for group II. Mean micro strains recorded at the loaded side were significantly lower in group II in comparison to group I. This is explained by the higher modulus of elasticity of zirconia (220 GPa) in comparison to cobalt-chromium alloy (209 GPa) which generates fewer stresses to supporting structures [16]. Materials with low young's modulus values (slope of stress-strain curve) can absorb more energy (area under stress-strain curve) especially if it can deform freely which means less energy will be transferred to the next part of the system [13]. Our results in strain analysis are in line with a previous study by Tarek A. Soliman & Raafat A. Tamam et al [17] - which concluded that using resilient crown material reduces the stresses on the bone.

CONCLUSION

CAD/CAM milled zirconia and Co-Cr cast metal attachments showed a different distribution of forces as the zirconia attachment transmits fewer stresses to the loaded and unloaded sides compared to the metal attachment.

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