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COMPARATIVE STRESS ANALYSIS STUDY BETWEEN DIFFERENT COPING MATERIALS IN COMPLETE OVERDENTURE CASES (AN IN-VITRO STUDY)

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ABSTRACT

This study aimed to evaluate stresses induced on the supporting area in case of using three different coping materials (zirconia, metal and PEEK) to cover prepared canines supporting lower complete overdentures with the goal of assessing the strains placed on the supporting area. Three casts made of epoxy resin were created to depict fully edentulous lower arches, with the exception of the left and right canines. For simulation of periodontal ligaments and alveolar mucosa rubber foundation material was used. A zirconia post and coping was built on both canines for the first cast; a nickel-chromium alloy was used on both canines for the second cast; and polyetheretherketone (PEEK) was used for the third cast with the use of four strain gauges that were fixed to each cast on the crest of the ridge. A loading machine and strain meter were used to evaluate the stresses imposed on the supporting areas and compare the three different coping materials. The first site was 5 mm distal to both canines, and the second was put on the first molar area bilaterally.

Data that was gathered was statistically examined. The three different types of coping materials differed significantly from one another. PEEK material had the highest value of stresses on the supporting ridge area, followed by zirconia, and metal copings had the lowest values. This can be explained by the fact that. Metal (Ni-Cr) has high mechanical properties regarding rigidity and hardness whil zirconia coping cracks with loading, followed by expansion and sealing, which reduces stress on abutment teeth and concentrates stress on the alveolar ridge. With regard to PEEK copings, a high modulus of elasticity produced a stress-breaking effect that minimized strains on the abutments and increased stresses on the remaining alveolar ridge.

KEY WORDS: Overdenture, PEEK, Zirconia, metal, strain gauge.

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INTRODUCTION

A prosthesis known as an Overdenture is one that rests on or covers one or more natural teeth, dental implants, or remaining roots which preserve the proprioception and the residual alveolar ridge. [1,2]

Teeth-supported overdentures are one of the finest treatment alternatives for elderly patients with few remaining teeth. It strengthens the dentures' stability and maintains the alveolar ridge. In comparison to overdentures supported by implants, it is easy to use and reasonably priced. The patient feels satisfied knowing that some of his natural teeth are still there. By using copings on the remaining teeth, we can improve the denture's stability and support while maintaining the structure of the remaining teeth from the oral environment [3].

Transition from natural teeth to suddenly become edentulous and wearing complete denture is often a traumatic physical and psychological experience for the patient.[4]

Over dentures that receive support from both periodontal and mucosal tissues offer numerous advantages when compared to complete dentures. These advantages include enhanced functional stability, improved retention, and increased chewing efficiency.[5]

Teeth that have become loose due to bone loss can be suitable for supporting overdentures when the height of the clinical crown is reduced to match the level of the ridge. Among all the designs, the short coping design exhibited the lowest level of stress. This design reduces horizontal torque on the roots and facilitates easy maintenance of oral hygiene.

Different methods were employed in the preparation of the oral cavity to accommodate the overdenture, which included simple tooth modification, endodontic therapy with an amalgam plug, or the use of a cast coping with or without an attachment.[6]

The use of extra coronal restorations (copings) serves as a protective barrier against oral microorganisms, preventing their penetration into overdenture abutments.[7,8,9,10] A comprehensive assessment was conducted to evaluate the occurrence of secondary caries and periodontal conditions in relation to metal copings and composite resin copings used on abutment teeth for overdentures. The results revealed no significant statistical variance between the two materials.[11]

Additionally, the inclusion of fluoride-releasing substances in coping materials can effectively reduce the occurrence of secondary caries and enhance the overall periodontal health.[12] Nevertheless, the presence of abutment teeth and metal copings within denture bases can result in the occupation of space and potentially serve as the pivot point for the movement of overdentures. Consequently, the acrylic resin surrounding the abutment teeth in overdentures may exhibit a thinner composition compared to conventional dentures in corresponding regions, thereby increasing the vulnerability to deformation or fracture in areas experiencing the highest levels of strain.[13,14,15,16]

Numerous studies have indicated that the highest level of strain is present beneath the surface of the overdenture, specifically near the upper portion of each coping.[17] Clinical trials have suggested enhancing the mechanical properties of the overdenture base material by reinforcing it. [18, 19, 20]

Several in vitro methods have been employed to evaluate the biomechanical load and stress exerted on natural teeth and the supporting ridge. These techniques include photo-elastic analysis, finite element analysis, and strain gauge analysis.[21,22]

Insufficient clinical studies have been conducted to evaluate zirconia as a coping material under overdentures, despite its numerous advantageous properties. Zirconia exhibits excellent biocompatibility and aesthetic properties, along with high mechanical strength.

Additionally, its favorable light dynamics, high fracture toughness, resistance to wear and fracture by fatigue loading, and low tendency to plaque accumulation make it a highly desirable material for various applications[23,24]. Zirconia exhibits mechanical properties that closely resemble those of metals, leading to its designation as 'ceramic steel' [25].

The utilization of computer aided designing (CAD) and computer aided manufacturing (CAM) facilitated the manipulation of various high-quality materials, particularly ceramics, in a more convenient manner [26].

Limited clinical follow-up data exists regarding the complications linked to overdentures and abutment teeth restored with metal copings, encompassing both post-procedural and prosthetic issues[27,28,29,30]. Additional research is thus required to adequately strategize prosthetic and preventative measures that cater to the requirements of denture wearers who utilize overdentures with metal copings.

Aim of the work:

The objective of this research is to assess the impact of various post and coping materials on the distribution of stress on the supporting residual alveolar ridge in cases of lower complete overdentures.

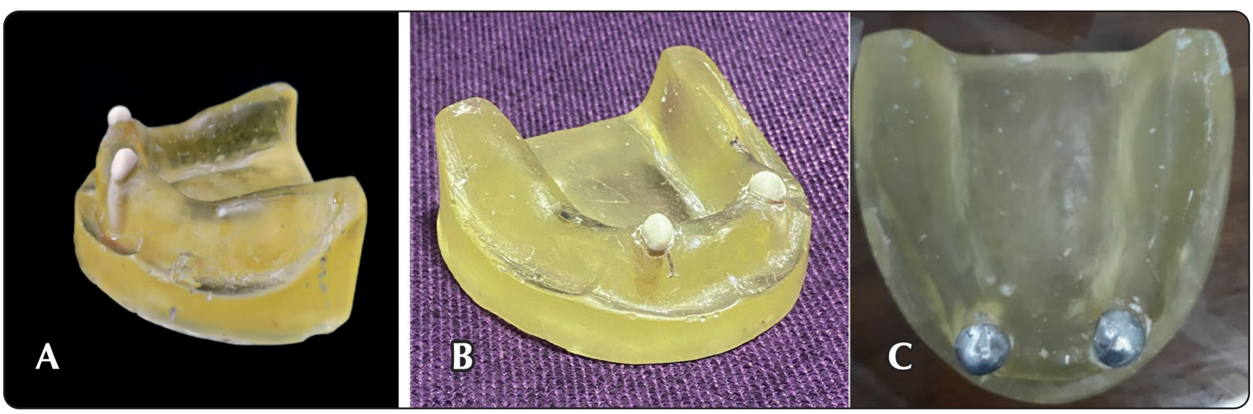
MATERIALS AND METHOD

Model fabrication:

Three mandibular models were created utilizing Epoxy resin to replicate a completely edentulous mandibular arch, with the exception of two canines that were retained (fig. 1). The model was meticulously crafted to imitate the oral cavity [31]. A freshly extracted two mandibular canines (length 25 mm) were selected and endodontically treated.

A 4 mm coronal reduction was carried out, followed by the creation of a 12 mm post space. This was achieved using duplication material and auto polymerizing polymethylmethacrylate resin. To simulate the periodontal ligaments of the artificial canines, a uniform layer of 0.3 mm silicone material was added around the roots. Additionally, a 2-millimeter layer was removed from the model's surface, which will later be replaced with mucosa-simulating material. This will be accomplished by applying an even layer of 2 mm silicone material over the ridge area.[32]

After scanning the initial model of the prepared abutments, the zirconia posts and copings were produced using CAD CAM technology with standardized parameters [33, 34]. (fig 1-A)



A: Zerconia post &coping. B: PEEK post&coping. C: Metal post &coping.

Fig (1): Epoxy resin casts with different posts and copings.

The second and third models were replicated using solid stone as a base, on top of which PEEK posts and copings were fabricated for the second cast, while posts and metal copings were fabricated for the third cast. (Fig.1-B&C)

Grooves and tunnels were created on the model to simplify the installation of strain gauges, and measurements were taken after the abutments' roots were prepared [35,36].

Mandibular Overdenture Construction:

Zirconia posts and cores, metal posts and cores, and PEEK posts and cores were affixed onto their respective Epoxy casts. Subsequently, the three mandibular models were replicated into three identical stone casts. Overdentures were fabricated for all casts and subsequently adjusted to fit their corresponding Epoxy casts. (Fig 2)

Linear gauges* were utilized in this study for strain analysis. These gauges had specific dimensions, with a length of 3mm, width of 1mm, and resistance of 120 Ohm. To establish a connection, they were linked to lead wires. In order to facilitate the analysis, grooves were created in each epoxy model at two distinct locations. The first groove was positioned 1mm away from the distal side of the first premolar, extending deep into the epoxy cast base and running parallel to the long axis of the tooth. The second groove was placed on the crest of the ridge in the first molar area [37].

All strain gauges were attached to the epoxy resin model using a precise application of cyanoacrylate adhesive **.

The loading points were subjected to vertical static loads ranging from 0 to 100 Newton. The digital loading device used for this purpose was the Universal testing machine***, which consisted of a base, frame, model fixture, and the loading point. To measure the strain, four strain gauges were integrated into each cast and positioned within vertical grooves that were created in the epoxy resin models.

A bilateral load of 70 N was applied by the loading device. The model was connected to the lower part of the universal testing machine, and the strain meter was used to connect the lead wires of each active strain gauge. (fig.3)

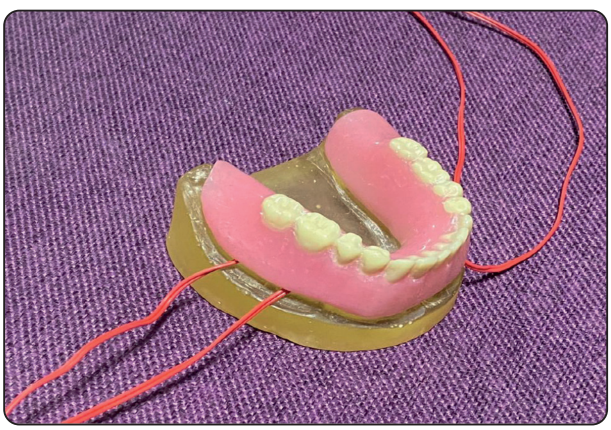


Fig.(2) Overdenture adapted to the Epoxy resin cast .

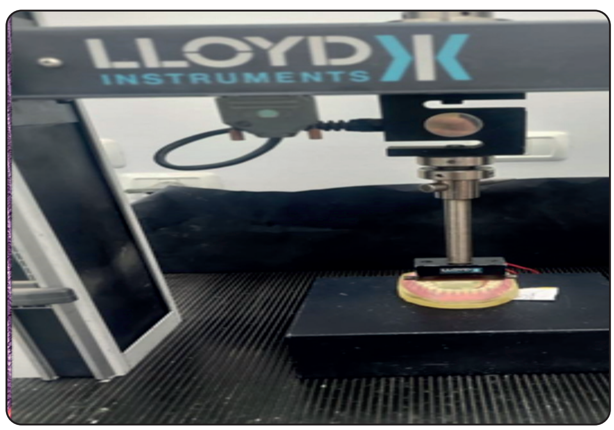


Fig.(3) The digital loading device.

* Koyoma Strain Gauges, Japan
** CC-33A, EP-34B; Kyowa Electronic Instruments Co., Ltd
*** LLOYD Instrument. LTD. UK. LRX. Plus.

Bilateral vertical loads of 70 N were applied at a constant rate of 10.0 mm/min. A standardized strain meter was utilized to measure the resulting strain. Upon application of the load, the micro-strain readings were recorded. The Strain meter was connected to a personal computer with the assistance of a specialized software, enabling the visualization of the obtained microstrain readings. The measurements were repeated 5 times, with a minimum of 5 minutes allocated for recovery and heat dissipation. The mean of the recorded micro-strain values underwent statistical analysis. The same steps were repeated for all casts. [37]

Sample size calculation:

Sample size calculated depending on a previous study done by Radwa et al., 2019[38] as reference. According to this study, the minimal accepted sample size was 9 per group, when mean and standard deviation of group 1 was (167±9.66), while the mean and standard deviation of group 2 was (150±7.74) with 1.48 effect size when the power was 80% & type I error probability was 0.05. The Independent t test was performed by using G Power 3.1.9.7.

Statistical Analysis:

Statistical analysis was performed with SPSS 20[*], Graph Pad Prism[**] and Microsoft Excel 2016[***]. Data revealed as means and standard deviations. Exploration of the quantitative data was performed using Shapiro-Wilk test and Kolmogorov-Smirnov test for normality which revealed that the significant level (P-value) was insignificant as P-value > 0.05 which indicated data originated from normal distribution (parametric data). Accordingly, comparison between different groups was performed by using One Way ANOVA test followed by Tukey`s Post Hoc test for multiple comparisons.

* Statistical Package for Social Science, IBM, USA.
** Graph Pad Technologies, USA
*** Microsoft Co-operation, USA.

RESULTS

During this study, mean ± standard deviation of stresses induced within (Zirconia) group were (151.5±19.44) which ranged from (120) minimally to (180) maximally. While for (Metal) group, mean ± standard deviation of stresses induced were (96±3.10.08) which ranged from (80) minimally to (112.5) maximally. Finally, with (PEEK) group, mean ± standard deviation of stresses induced were (198±26.97) which ranged from (160) minimally to (235) maximally, as listed in table (1) and showed in figure (1).

Using One Way Analysis of Variance (One Way ANOVA) revealed the significant stresses induced within the (PEEK) group followed by (Zirconia) group and (Metal) group as P-value < 0.05, listed in table (1). While multiple comparisons were performed using Tukey`s post hoc test which revealed significant difference between different groups as P-value < 0.0001, listed in table (2).

TABLE (1) Descriptive Analysis of Strain Gauge Values of Different Groups:

	Zirconia	Metal	PEEK
N of values	10	10	10
Min	120.0	80.00	160.0
Med	151.3	96.25	196.3
Max	180.0	112.5	235.0
M	151.5±19.44	96.00±10.08	198.0±26.97
SD	19.44	10.08	26.97
SEM	6.149	3.189	8.529
Lower 95% CI	137.6	88.79	178.7
Upper 95% CI	165.4	103.2	217.3
P Value		<0.0001 *	

N; Number, Min, Minimum, Med; Median, Max; Maximum, M; Mean, SD; Standard Deviation, SEM, Standard Error of Mean, CI; Confidence Interval

TABLE (2) Multiple Comparison Analysis of Strain Gauge Values of Different Groups:

Tukey's multiple comparisons test	Mean Diff.	95.00% CI of diff.	P Value
Zerconia vs. Metal	55.50	33.26 to 77.74	<0.0001**
Zirconia vs. PEEK	-46.50	-68.74 to -24.26	<0.0001**
Metal vs. PEEK	-102.0	-124.2 to -79.76	<0.0001**

Highly Significant Difference using Tukey`s Post Hoc Test as P<0.001.

Strain Gauge Analysis

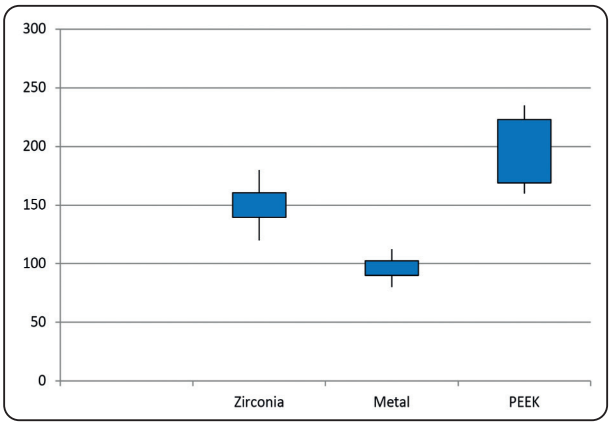


Fig. (4) Box and Whisker Chart revealing Descriptive Analysis of Strain Gauge Values of Different Groups

DISCUSSION

The fabricated models successfully achieved the most accurate simulation of natural oral conditions. The elastic modulus of the resin cast material is suitable for a bone analog material. [39]. To simulate the periodontal ligaments, the roots were coated with a 0.3 mm layer of light body silicone rubber impression material, while a 2mm layer of the same material was applied to cover the residual ridges for the simulation of mucosa. [40]

The rosette of the strain gauge was affixed onto flat, prepared surfaces in order to reduce the likelihood of acquiring additional strain caused by attaching it onto a curved surface [40, 41]. In our study, the loading device utilized the standard average bite force of 70 N [42] .

This research utilized the LLOYD digital loading device to apply a progressively increasing load for its user-friendly digital operating mechanism and high precision [43].

A five-minute interval was provided between each reading to allow for the release of stresses and heat from the strain gauges [44] .The central occlusal fossa of the first molar served as the designated loading site to ensure reproducibility and to accommodate the positioning of the loading pin.

The results of the study indicated that the metal coping exhibited the highest level of stress transfer to the supporting ridge, followed by the zirconia copings. On the other hand, the PEEK coping material demonstrated the least amount of strain transferred to the supporting ridge. Notably, there was a significant distinction observed among the three materials.

The reason for these results can be attributed to the inherent properties of the three different materials and how they respond to different types of stress. The metal (Ni-Cr) is known for its high level of hardness and rigidity, which provides a strong base for the overdenture. As a result, a large portion of the applied force is transferred to the supporting abutments, while very little stress is placed on the supporting ridge area.

Zirconia exhibits mechanical properties that closely resemble those of metals. It possesses an impressive tensile strength of 900-1200 MPa and a compression resistance of approximately 2000 MPa. [45] Applying force on the surface of zirconia results in a transition to various crystalline structures, causing a change in volume of the crystals. When stress is applied to the surface of zirconia, the energy from cracking causes it to shift to a mono-clonic phase. This results in expansion, effectively closing the crack. This process helps to relieve some of the applied stresses on the supporting abutment and allows for the transfer of additional stresses to the supporting ridge area.

Compared to conventional metal and ceramic dental materials, Polyetheretherketone (PEEK) demonstrates reduced stress shielding as a result of its elastic modulus, along with its impressive flexural strength of 183 MPa. PEEK functions as a stress-relieving component, effectively reducing the amount of stress transferred to the supporting overdenture abutments while increasing stress transfer to the supporting ridge area [46,47,48,49] .

This study has its limitations due to its in vitro nature, neglecting the impact of individual oral cavity conditions. Therefore, it is imperative to conduct additional clinical trials.

CONCLUSIONS

Based on the findings of this in vitro study, it can be inferred that metal copings are the optimal selection for overdenture cases. This is due to their capacity to reduce the transmission of stress to the supporting ridge area, thereby preserving the remaining residual ridge. In contrast, zirconia and PEEK coping-supported overdentures do not exhibit the same level of effectiveness in this regard.

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Conflict of interest:

The authors declare that there is no conflict of interest.

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