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EFFECT OF INLAY, ONLAY, AND ENDOCROWN RESTORATIONS ON THE MODE OF FAILURE AND FRACTURE RESISTANCE OF ENDODONTICALLY TREATED MAXILLARY PREMOLAR TEETH. AN IN VITRO STUDY

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ABSTRACT

Aim: To assess the impact of various restoration designs on the fracture resistance and failure mechanisms of maxillary premolars that have undergone endodontic treatment.

Methods: Eighteen extracted upper premolars were used in the current study. All teeth were endodontically treated. Using a modified lateral compaction approach, the root canals were obturated with the matching gutta percha cones after being expanded with Protaper Next files up to #X3. Afterwards, teeth were randomly assigned to either of 3 equal groups according to the restoration design. Group1, EC: Endocrowns, Group2, O: onlays and Group3, I: inlays. All restorations were fabricated from IPS e-max press. Samples underwent thermocycling before a universal testing machine applied a compressive stress at a 30-degree angle to the teeth's long axis. Data were collected and analyzed statistically by one-way ANOVA and Tukey post-hoc tests.

Results: the inlay group failed at a significantly lower load compared to both onlay group and Endocrown group, (p=0.032). Regarding the failure mode, statistical analysis revealed a significant difference amongst groups. All samples in "EC" group (100%) had Fractured tooth & restoration above CEJ, all samples in "I" group (100%) had Fractured tooth & restoration below CEJ, while in "O" group, most samples (66.666%) had Fractured tooth & restoration above CEJ while the remainder (33.333%) showed only a fractured restoration.

Conclusion: When compared to inlays and onlays, endocrowns had the highest mean fracture resistance; however, the difference was not statistically significant when compared to onlays. When compared to both inlays and endocrowns, onlays had the failure mode that was most favorable.

Recommendation: Based on the current study's findings, onlays could be suggested as a final restoration for maxillary premolars following endodontic therapy.

KEYWORDS: Endodontically treated maxillary premolar, endocrown, inlay, Onlay, Fracture Resistance, Mode of Failure

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INTRODUCTION

Restoring endodontically treated teeth is a critical part of dental practice. A wide range of situations, complexities, and treatment options exists making restoration of those teeth more complicated especially with the extensive tooth structure loss either due to the endodontic treatment itself or due to caries [1]. Therefore, restoring a tooth after endodontic treatment is almost always a challenge. Endodontic treatment is usually carried out in teeth that have been destroyed to various extents by dental caries, in addition, the loss of proprioception makes non vital teeth less capable of withstanding increased loads[2]. Moreover, chemicals used during endodontic treatment, intra canal medications and irrigating solutions, can affect the physical properties of dentine as well as its chemical composition making it more brittle and liable to fracture[3].

After root canal treatment, clinicians should be able to restore teeth to their original form while maintaining proper function and pleasing esthetics. The final restoration should provide satisfactory retention without inflicting any harm on the remaining hard tissues. Furthermore, it must prevent coronal leakage and possible tooth fractures[4]. The optimal post endodontic restoration should be selected based on the remaining sound tooth structure, its position in the dental arch as well as functionality and esthetics, especially when inadequate restorative treatment has been considered one of the most common causes of endodontic treatment failure[5]. It has been indicated, in teeth where marginal ridges and other supporting structures were lost, that restoration should at least provide cuspal coverage to protect the tooth against occlusal forces, preventing catastrophic fractures. [6]

Different masticatory forces applied to the occlusal surface of posterior teeth make them exhibit different restorative needs. More conservative designs were suggested over the past 30 years to replace the conventional full coverage ones, since improvements in adhesive philosophy and the ability of recent adhesive systems to provide strong bonding is changing the old concept that after endodontic treatment all teeth must be restored with post crowns. Adhesion eliminates the need for aggressive macro-retentive techniques as well[7].

Several indirect restorations can be used to restore endodontically treated teeth, amongst them onlays, inlays, overlays, and endocrowns are most commonly used[8]. These restorations may be divided into three categories based on the amount of cusp coverage; overlays, where all cusps are covered, onlays, where at least one cusp is covered, and inlays, where there isn't any cusp coverage [9,10]. Endocrowns on the other hand, bring together the intra radicular post, core and crown in one unit, where the pulp chamber is used to improve retention through a wider surface area for adhesion thus increasing stability. Minimally invasive restorations for posterior teeth have the advantages of conserving tooth structure and improving stress distribution [11,12].

The optimal material to restore an endodontically treated tooth must provide the restoration with the highest strength to withstand function while preserving as much of the tooth structure as possible[11].

Glass ceramics were strengthened with either leucite or high-strength lithium disilicate to enhance their flexibility and fracture resistance. Thus, making them more capable of withstanding occlusal forces during function [13]. In fact, indirect ceramic restorations have surpassed conventional restorations in terms of mechanical properties, biocompatibility, and esthetics.

The current literature still lacks enough data about the impact of preparation designs on the fracture resistance of endodontically treated teeth, despite the presence of some research about the fracture resistance of endocrowns [14]. To assist clinicians in choosing the best designs with biomechanical characteristics that are closest to those of natural dentition, more investigations are required. The current in vitro study aimed at evaluating the impact of three preparation designs namely, inlays, onlays, and endocrowns on the failure mode and fracture resistance of upper premolars that had endodontic treatment. The null hypothesis was that there would be no discernible differences in fracture resistance and failure mode between the three restorations.

MATERIALS AND METHODS

Sample size calculation and preparation of samples

The study protocol was approved by the ethical committee at the Faculty of Dentistry, Egyptian Russian University, Egypt (number 8/2023). Based on the data from a previous study [12] , the mean (Sd) fracture resistance of Endocrown-restored endodontically treated was 1300.53/ (298.167). Using an effect size of 1.1305139 obtained from that study, a type I error of 0.05, and a power of 0.95, a total of 18 samples were required to detect a significant difference among groups regarding fracture resistance.

Eighteen freshly extracted maxillary premolars were included in the study. All teeth were disinfected using 5.25% sodium hypochlorite (NaOCl) then ultrasonically scaled to remove any surface debris. Absence of external defects such as caries, fractures, cracks, incompletely formed apices, or resorptions was confirmed after examination under a surgical operating microscope (Zumax, Zumax Medical Co., Ltd., Jiangsu, China) at 12x magnification. The inclusion criteria included straight roots with completely mature apices and no evidence of internal root calcification or internal or external root resorption.

Access cavity preparation was performed in all teeth by size 2 round burs and fine tapered stones with rounded ends. To determine the working length, 1mm was subtracted from the length of a patency K-file (Mani, Japan) that coincides with the apex. Instrumentation was done using the ProTaper Next rotary file system (Dentsply/ Maillefer, Switzerland) up to size X3 at 300 RPM and 200 gcm, as recommended by the manufacturer. During preparation, irrigation was done with 2.5% sodium hypochlorite (Clorox Co., 10th of Ramadan, Egypt). The smear layer was removed using 5 ml of 5.25% NaOCl and 5 ml of 17% EDTA (Cerkamed, Pawłowski, Poland). After complete preparation, obturation was done using the modified lateral compaction technique with resin sealer (AH Plus, Dentsply/Sirona) and matching X3 master cones. A #30 spreader was used to create a space for auxiliary cones to be applied for maximum adaptation in the coronal third.

All teeth were prepared with a standard MOD cavity with tapered diamond burs (6-degree taper) at high speed, with a minimum remaining thickness of 2 mm in the buccal and lingual walls and a 3-mm depth of the horizontal pulpal floor. Proximal boxes were prepared with an isthmus depth of 2 mm. Lingual and buccal axial walls were prepared to be divergent. The supragingival margin of all preparations was set at 1 mm, directly above the cemento-enamel junction. For onlays, a 90-degree butt joint margin was made in addition to a 2 mm reduction of both palatal (functional) and buccal (nonfunctional) cusps. [11]

For Endocrowns, a 2-mm occlusal reduction was done in all teeth, then the pulp chambers were prepared so that the walls would have a 10-degree coronal divergence utilizing a tapered stone with rounded end to eliminate undercuts. The preparation was oval shaped with 4-5 mm depth from the cavosurface margin, this was confirmed using a graduated periodontal probe, without further drilling inside the canal. A finishing stone was used to smoothen and finish the internal line angles [15]. Vinyl polysiloxane elastomeric impressions (EliteHD+, Zhermack/Italy) were made. The IPS E.max press restorations for all samples were fabricated by Programat press furnace (EP 3010, Ivoclar; VivadentAG).

Cementation procedures:

Each restoration's fitting surface was treated for 20 seconds using 8% hydrofluoric acid (Bisco Porcelain Etch). [15], This was followed by a water rinse, oil, and moisture-free air drying, and repeated until the restoration took on a white, frosty look. After that, the etched ceramic surface was brushed with Porcelain Silane BisCem (Bisco, United States) for one minute, then thoroughly dried in the same manner described earlier, as recommended by the manufacturer [7].

All teeth were subjected to selective etching for enamel only with Scotchbond (3MESPE) Etchant as instructed by the manufacturer. After 30 seconds, thorough washing was done by an air stream for 15 seconds, followed by air-drying.

Cementation was done using Total Cem resin cement (Itena, France). Auto-mixing tips were used to dispense the cement directly on each surface of the restoration. Followed by its gentle seating on the prepared tooth to let the luting cement flow from all sides. When the restoration was properly seated, any excess cement was carefully removed with a hand scaler before light curing for a total of 100 seconds (20 seconds\surface) using a light-curing unit (700 Mw\Cm2. Elipar2500)[7].

Thermo-cycling procedures

After the complete setting of the cement, artificial aging of all specimens was carried out in a masticatory simulator (Esetron Smart Robotechnologies, Ankara, Turkey). Both mechanical and thermal aging are part of the process (TCML). A total of 5000 cycles of thermal cycling were performed. Every water bath (Robota automated thermal-cycle, BILGE/Turkey) has a 25-second dwell time with a 10-second latency. Five degrees Celsius was chosen as the low temperature point and fifty-five degrees Celsius as the maximum temperature point[10]. Subsequently, each sample was mounted on a computer-controlled testing machine (Model no. 3345; Instron Industrial Products, Norwood, USA) with a load cell of 5000 N. Data recording was done using computer software (Bluehill Lite Software, Instron). A tightening screw was used to attach samples to the lower fixed part of the testing machine. A metal rod with a 3.6 mm spherical end that was fixed to the upper mobile part of the machine was used to apply a compressive load to the occlusal surfaces in order to test fracture resistance. The rod moved at a cross-head velocity of 1 mm/min, while a sheet of tinfoil was placed in between to ensure uniform stress distribution and minimal transmission of local force peaks. A clear cracking sound indicated the load at failure, and a fast decline in the load-deflection curve, recorded with the use of computer software (Bluehill Lite Software, Instron Instruments), verified that load.

RESULTS

The load to fracture data is represented in (table 1), there was a statistically significant difference between the inlay group which showed the lowest mean load to fracture, and the other two groups. The Endocrown group exhibited the highest mean load required for fracture. However, this difference was not statistically significant compared to the onlay group.

Table 1: Mean values of load to fracture using one way ANOVA test in the three groups.

	Endocrown	Onlay	Inlay
Mean ±SD	726 ±379^{A}	627 ±354^{A}	233.1 ±101.3^{B}
P-Value	0.032		

Means that don't share same letter are significantly different. Pair wise comparison was done using Post Hoc analysis.

Regarding the failure mode, a significant difference was found among groups. 100% of specimens in the Endocrown group had Fractured tooth & restoration above CEJ and 100% of specimens in the Inlay group had Fractured tooth

Table 2: Comparison between number and frequency of different modes of failure using one way ANOVA test in the three groups:

		Endocrown	Onlay	Inlay	P-value
Fractured restoration	No.	0	2	0	<0.05
	%	0% A	33.333% B	0% A	
Fractured tooth & restoration above CEJ	No.	6	4	0	
	%	100% A	66.666% A	0% B	
Fractured tooth & restoration below CEJ	No.	0	0	6	
	%	0% A	0% A	100% B	

Means that don't share same letter are significantly different. Pair wise comparison was done using Post Hoc analysis.

& restoration below CEJ "catastrophic failure", while the majority of specimens in the Onlay group 66.666% had Fractured tooth & restoration above CEJ and the remaining specimens 33.33% had fractured restoration only "favorable mode of failure" (table 2).

DISCUSSION

Selecting a restorative material for teeth with endodontic treatment requires careful planning, which may pose a problem for the restorative dentist. It has always been a challenge to determine the best conservative preparation and the optimal material to use to minimize the influence on physical properties of teeth following endodontic treatment [16,17]. Direct restorative treatments demonstrated lower fracture resistance in posterior teeth after endodontic treatment when compared to indirect techniques[18].

Endodontically treated teeth may fracture for a variety of reasons, most of which are beyond the clinician's direct control [19]. Proper material selection and ideal tooth preparation are two key elements influencing fracture resistance. Therefore, research is still ongoing to determine the best restoration design as well as the best restorative material for teeth that have had root canal therapy in order to increase the teeth's resistance to fracture. [11] In order to determine the best cavity design for teeth undergoing endodontic treatment, this study was carried out. A balance between maintaining tooth structure and optimizing restoration strength is also necessary when selecting materials for endodontically treated tooth restorations [20].

Conservative restorations such as inlays, onlays, and endocrowns help to preserve the remaining dental tissues and lessen the amount of tooth structure that is removed [11]. Compared to traditional crown preparation, the ferrule effect is avoided, leaving more healthy tooth structure available for the bonding procedure [19,21].

Maxillary premolars are more susceptible to fracture as they experience both compressive and shear forces during function [22]. Additionally, prior research demonstrated that teeth with MOD cavities that have undergone endodontic treatment lose supporting elements like marginal ridges and the roof of the pulp chamber which severely weakens them increasing the possibility of fracture [23,24]. Also, there is still no consensus on the best prosthetic procedure for posterior teeth, especially premolars that have undergone endodontic therapy. Nonetheless, it has been determined that a procedure's impact on the survival rate of such teeth increases with its degree of conservatism towards the coronal tooth structure. [25].

That's why in this study, maxillary premolars were used to test fracture resistance in a very demanding clinical setting. MOD cavities were made in all three different preparation designs: inlay, onlay, and endocrown.

An important part of any in vitro study about subcritical fracture formation in ceramic materials that may happen during repeated loads during mastication is artificial aging. In this study, each specimen was subjected to dynamic loading and thermal cycling to see how it would react in real-life clinical settings that were repeated [26].

Thermocycling and cyclic loading were coupled in earlier research to simulate artificial aging [27–29]. In the current study, specimens were subjected to 5000 thermocycles, a number that was previously found to reflect the effects of a six-month period of intraoral use [30]. The average number of human chewing cycles is assumed to be between 800-1400 cycles per day. Cyclic loading with an increasing number of cycles had an impact on propagated fractures and reduced the strength of ceramic restorations [31]. The size and load of the indenter, as well as the frequency and duration of loading, are all subject to various criteria. As a result, comparing and assessing the actual consequences is still difficult. [32].

Inlays and onlays are alternate restorations depending on the quantity of tooth structure that is still present in teeth that have had endodontic therapy. According to recent research, there is no significant difference in the fracture strength of sound teeth and endodontically treated teeth restored with ceramic inlays; nevertheless, the latter may have more catastrophic fractures. [33]. The residual wall thickness, which should be greater than 2 mm, determines the fracture resistance of teeth with inlay preparations. Furthermore, cuspal covering is essential for big preparations in order to avoid potential fractures. When there is full occlusal covering, the stress distribution pattern is at its most advantageous [34,35].

Advancements in adhesive procedures impact the restoration of teeth that have undergone endodontic treatment because the adhesive procedure provides micromechanical and molecular retention rather than relying just on mechanical retention as it did previously. Keeping this in mind, the greater the interface area (the region between the restoration and the tooth), the greater the likelihood that the restoration will survive[11]. Bitter et al [36] reported that onlays with prepared proximal boxes and cusp coverage that still include the palatal and buccal walls are superior to inlays without cusp coverage.

Using lithium disilicate is declared as an effective strategy in literature. Regarding their adhesive qualities and ability to promote micromechanical interlocking with resin cement, lithium disilicate-based ceramics are thought to be among the finest restorative materials for indirect restorations. The IPS e.max press is the best choice for making the best e.max restorations with high flexural strength (360–440 MPa), high fracture toughness (2-4 MPa), and strong resistance to thermal shock because it uses a lost wax manufacturing method and better detail reproduction. Microcrack propagation is also reduced. It is the benchmark of all glass ceramic restorations because of these attributes, as well as its excellent aesthetic features and bonding availability.[21,37].

The results of this investigation showed that endocrowns had the highest fracture resistance compared to onlays and inlays though it wasn't significantly higher than fracture resistance of onlays. Fracture resistance differed with different preparation designs, which meant the null hypothesis was rejected. The results of this study were consistent with earlier research that found that endocrowns had the highest fracture resistance [38,39].

The mean fracture strength of endocrowns was 726 ±379N, inlays was 233.1 ±101.3B N, and onlays was 627 ±354N. These values fall within the same range that was found in other research [21,40]. Furthermore, compared to inlays, the fracture strength of endocrowns was noticeably greater. This could be explained by the extra retention gained by the extension of endocrowns into the pulp chamber and the distinct preparation design. Although not significant, the fracture resistance of endocrowns was higher than that of onlays; in earlier research, the pulp chamber extension of endocrowns measured 4 mm and that of onlays measured 2 mm. The deeper extension of endocrowns and its unique preparation design may as well explain its higher resistance compared to onlays [41,42]. Furthermore, zirconia endocrowns extending 5 mm into the pulp space showed better fracture strength than those extending 3 mm (Haralur et al) [31].

According to the current study's findings, endocrown has stronger fracture resistance than some other research's findings. Lithium disilicate endocrowns have stronger fracture resistance than onlays and inlays, according to the findings of Hamdy et al [25]. With the application of 200, 500, and 800 Newton forces, endocrown restorations demonstrated a better stress distribution in the enamel and dentin in a 3-dimensional finite element analysis carried out by Prina et al. [40]

Yoon et al.'s 3D finite element study discovered that onlay cavity designs were more effective in protecting teeth than inlay designs. [43] According to other research, when repairing teeth that have undergone endodontic treatment, endocrown has superior fracture resistance to traditional restorations [38,44]. Endocrowns' ability to tolerate compressive pressures as a result of their increased ceramic thickness and decreased number of interfaces with the restorative system may help to explain this outcome.

The mode of failure observed in Group 1 (Endocrowns) indicated tooth and restoration fractures, which may or may not be treated based on the quantity of tooth structure that remains. Less catastrophic fractures were seen in Group 2 (Onlay), where a more favorable fracture may hypothetically permit a second restoration of the tooth. But in Group 3 (the inlay) worst root fractures render the tooth irreparable and necessitate extraction.

The inlay restoration performed the worst, which may have been due to the preparation's geometric shape, which acts as a wedging force to fracture the tooth while it is under occlusal stress [12]. Despite the fact that forces on the onlay and endocrown oppose the wedging action produced by the internal restoration design by covering part of the buccal and lingual surfaces as well as the tips of the cusps, they are directed along the long axis [25].

Similar to the results of the current study, Keçeci et al.[45] found that ceramic MOD inlays significantly increased the number of untreatable fractures, which is consistent with the findings of the current investigation. Onlay restorations displayed a heterogeneous type of failure according to where the fracture lines were localized. They concluded that more favorably distributing stress and localizing fracture lines were made possible by cusp-covering restorations [46].

As an in vitro study, the current study has certain limitations with regard to simulating clinical conditions; further studies are needed to investigate the effects of long-term fatigue on lithium di-silicate restorations.

CONCLUSIONS

Endocrowns have the strongest fracture resistance, but not significantly more so than onlays. Onlays, on the other hand, displayed a more advantageous failure mode than endocrowns. Inlays had the poorest failure mode across all groups and a significantly lower load to fracture.

RECOMMENDATIONS

Within the constraints of this research, onlays, rather than endocrowns, should be the first restorative option for final restoration for maxillary premolars that have had endodontic treatment.

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