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Maged Galal Abdelmaksoud Elenany
BDS Oral and Dental Medicine, Misr International University, Cairo, Egypt

Karim Aboubakr Rabie
Associate Professor of Fixed Prosthodontics, Department, Faculty of Dentistry, Cairo University, Cairo, Egypt

Amina Abd-El-Latif Zaki
Professor and Head of Fixed Prosthodontics Department, Faculty of Dentistry, Cairo University, Cairo, Egypt

Corresponding Author:
Maged Galal Abdelmaksoud Elenany
BDS Oral and Dental Medicine, Misr International University, Cairo, Egypt

Fracture resistance and relative stiffness of root canal treated premolars restored with two different preparation designs of ceramic restorations: An *in vitro* study

Maged Galal Abdelmaksoud Elenany, Karim Aboubakr Rabie and Amina Abd-El-Latif Zaki

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Abstract
The restoration of endodontically treated teeth (ETT) has been a controversial topic for many years. It is known that vitality loss causes physical and structural changes affecting the dentin properties such as micro-hardness, modulus of elasticity and fracture toughness. Root filled upper premolars present specific challenges for the restorative dentist because in addition to esthetic considerations, cusp fracture was found to be more concentrated in these teeth. Furthermore, longitudinal root fractures are more common in upper premolars with narrow roots in the mesiodistal dimension.
Purpose: The aim of this in-vitro study was to measure the fracture resistance and relative stiffness of root canal treated premolars restored with two different preparation designs of ceramic restorations.
Methods: The present study was conducted using 16 extracted human maxillary premolars. Teeth were divided into two equal groups (N=8): Group (A) received an onlay with palatal cusp coverage and Group (B) received an overlay with total cuspal coverage. Lithium di-silicate CAD blocks were used to fabricate all the restorations and cemented using self-adhesive dual cure resin cement. All Specimens were then subjected to fracture with cross-head speed 1.00 mm/min.
Results: There was no statistically significance between the two preparation designs concerning the fracture resistance. While the relative stiffness results showed that the restored overlay (Group B) is significantly higher than the restored onlay (Group A).
Conclusion: Both partial coverage restorations designs (overlay and onlay) restored the relative stiffness of the tooth structure and could work as an alternative line of treatment for restoring endodontically treated maxillary bicuspids.

Keywords: Overlay, onlay, cuspal coverage, stiffness, fracture

1. Introduction
For many years, the restoration of ETT has been a contentious issue. Vitality loss is known to cause structural and physical alterations in the dentin's micro-hardness, elastic modulus, and fracture toughness. For the restorative dentist, upper premolars with root fillings provide special challenges because, in addition to aesthetic concerns, cusp fracture was found to be more prevalent in these teeth. Furthermore, longitudinal root fractures are more likely to occur in upper premolars with thin roots in the mesiodistal dimension [1].
Reeh *et al.* (1989) [2] determined that the marginal ridge integrity loss caused the greatest reduction of stiffness because of their anatomy, which makes cusp separation during mastication possible. Traditionally, the coronal restoration of ETT was mainly performed with metal or glass fiber-reinforced posts and cores [3]. With the development of adhesive dentistry, postless techniques for reestablishing ETT with a ferrule are becoming more prevalent. With a resin composite core build-up and a minimum of 2 mm of ferrule, teeth have been repaired without posts. In contrast to the idea of post-and-core build-ups, this approach appears to resemble the structure and biomechanical behaviour of a natural tooth more precisely [4].

Adhesive procedures are now frequently employed in ETT restoration to strengthen the stiffness of the restored tooth unit and preserve the repaired tooth from fracture in clinical service. This is thought to be especially important in the restoration of endodontically treated posterior teeth

It has been suggested that the pulp chamber be used to create and retain an endo-type" crown-a ceramic crown that extends into the pulp chamber for additional retention and resistance in the restoration of endodontically treated posterior teeth. [5] in order to avoid post canal preparation and benefit from the adaptability of CAD-CAM technology in the restoration of endodontically treated posterior teeth [6].

The biomechanical behavior of the restored tooth unit, whether with or without preservation of coronal tooth tissue, may be negatively impacted by the extension of restorations into the pulp chamber [7–9]. To prevent ETT fracture, full cuspal protection with an overlay restoration or crown is often recommended as soon as root canal therapy is done, especially with maxillary and mandibular premolars [10].

In the present lab-based investigation, maxillary premolar teeth that had been endodontically treated. They were restored using bonded ceramic onlays or overlays (ceramic partial coverage restorations with palatal cuspal coverage and ceramic partial coverage restoration with palatal and buccal cuspal coverage), including designs without pulp chamber extensions, to investigate into how well the repaired tooth units resisted cuspal stiffness and fracture resistance.

2. Materials and Methods

A total of sixteen extracted human maxillary premolars were collected and divided into two equal groups (N=8): Group (A) received onlay retained restoration with palatal cusp coverage and Group (B) got overlay restoration with complete cuspal coverage.

The strain was measured by using strain gauges under axial, compressive, non- destructive force (150 N with cross-head speed 0.5 mm/min) by using universal testing machine; in three instances: M1: Sound (unaltered) tooth sample, M2: Prepared tooth sample, and M3: Restored tooth sample. After M1, root canal treatment and preparation for the two groups were done. M2 was measured. Afterwards, the restorations were designed from exocad Dental CAD software.

Lithium di-silicate CAD blocks were milled using MCX5 milling machine and cementation was done. M3 was performed. All Specimens were then subjected to fracture with cross-head speed 1.00 mm/min. Fracture resistance test was performed using a universal testing machine a cross-head speed of 1mm/min till fracture occurred.

3. Statistical methods

Numerical data were explored for normality by checking the distribution of data and using tests of normality (Kolmogorov-Smirnov and Shapiro-Wilk tests). Strain and relative stiffness data showed non-normal (non-parametric) distribution while fracture resistance data showed normal (parametric) distribution For Parametric data, the data were analyzed and presented as mean, standard deviation (SD), median and range values. For non-parametric data, the data were analyzed and presented using Mann-Whitney U and signed rank tests for inter and intra group comparisons respectively. Statistical analysis was performed with R statistical analysis software version 4.1.3 for Windows [11].

4. Results

The buccal cusp of the restored teeth showed statistically significant higher relative stiffness values of (1.19±0.40) and (1.03±0.24) for the overlay and the onlay preparation groups respectively compared to that recorded for the prepared teeth for the overlay (0.57±0.21) and the onlay (0.86±0.92) preparation groups as demonstrated in Figure (1).

Regarding the buccal cusp of the prepared teeth, no statistical significant difference in the relative stiffness values was noted between the overlay and the onlay preparation groups, as observed in Table (1). As for the buccal cusp of the restored teeth, the overlay preparation group showed a statistically significant higher relative stiffness values than the onlay preparation group.

The palatal cusp of the restored teeth showed statistically significant higher relative stiffness values of (1.34±0.40) and (1.14±0.11) for the overlay and the onlay preparation groups respectively compared to that recorded for the prepared teeth for the overlay 0.64±0.26) and the onlay (0.90±0.68) preparation groups, as illustrated in Figure (2).

According to Table (2), we didn’t detected any statistical significant difference in the relative stiffness values was noted between the overlay and the onlay preparation groups concerning the palatal cusp of the prepared teeth. As for the palatal cusp of the restored teeth, the overlay preparation group showed a statistically significant higher relative stiffness values than the onlay preparation group.

In addition, no statistical significant difference in the fracture resistance values was noted between the overlay and the onlay preparation groups: at (P-Value = 0.379, Effect size = 0.454), as showed in Figure (3).

Multiple fracture modes were obtained mainly catastrophic failure occurs in most of the samples except one sample from Group (A). The obtained results were arranged in a table with multiple coulmns include: Speed head, maximum load, work to maximum load. The fracture pattern occurred in (93.7%) of the total samples, as described in Figure (4).

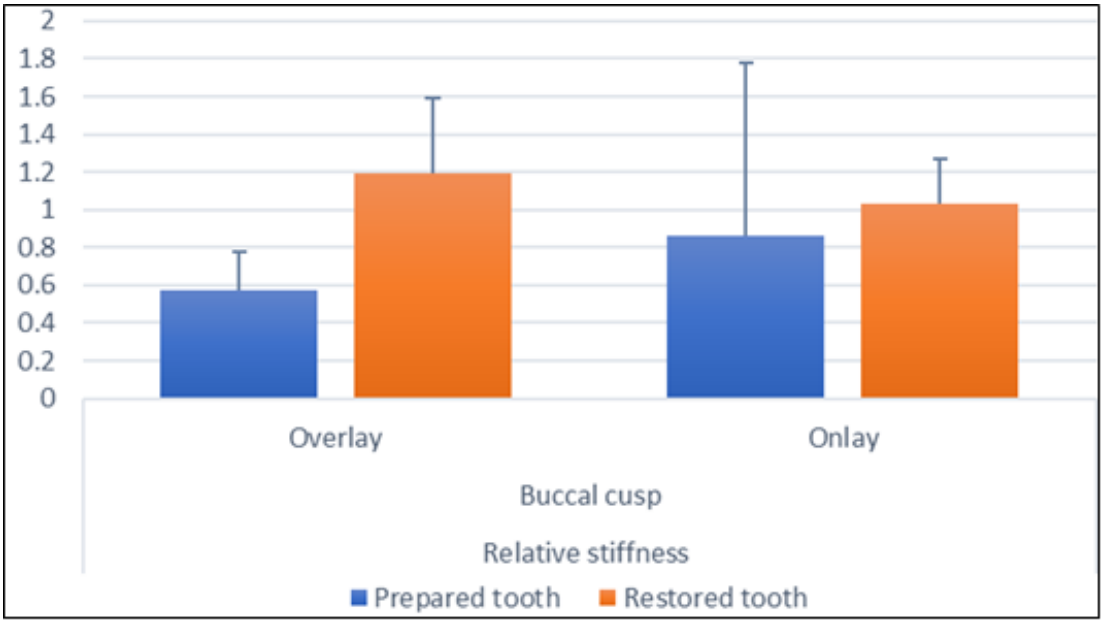

Fig 1: Bar chart showing mean and standard deviation values (error bars) for relative stiffness in buccal cusps

Table 1: The results of the signed rank tests the relative stiffness in buccal cusps of the two preparation groups

Preparation	Relative stiffness (Mean ± SD)	
	Prepared tooth	Restored tooth
Overlay	0.57±0.21	1.19±0.40
Onlay	0.86±0.92	1.03±0.24
U-Value	865.00	1058.50
P-Value	0.535ns	0.012*

*Significant ($p \leq 0.05$)/non-significant ($p > 0.05$).

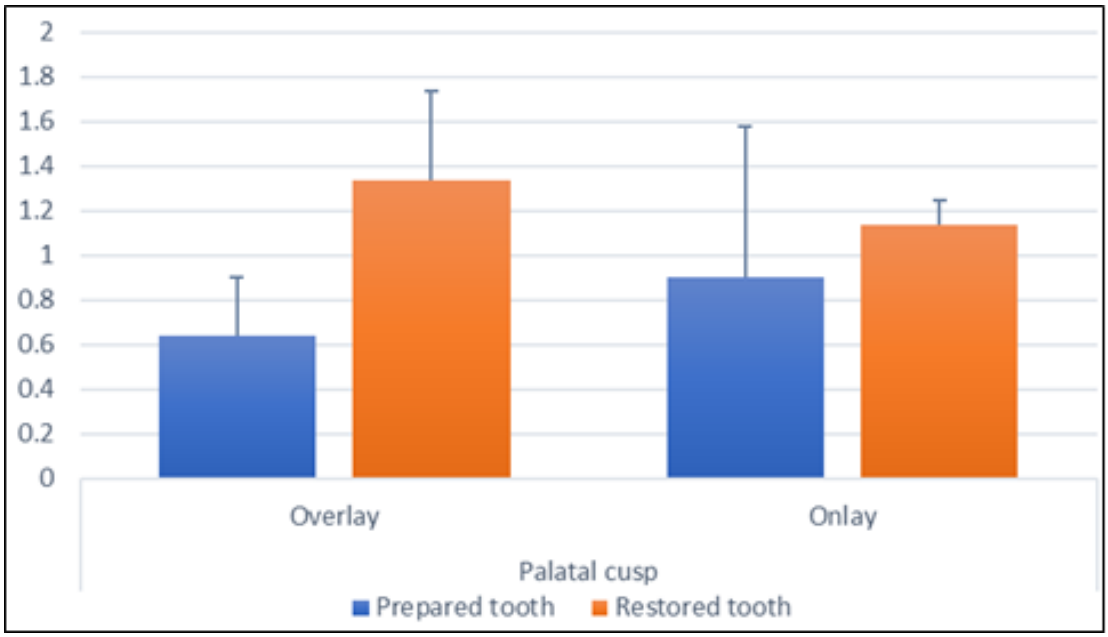

Fig 2: Bar chart showing mean and standard deviation values (error bars) for relative stiffness in palatal cusps

Table 2: The results of the signed rank tests the relative stiffness in palatal cusps of the two preparation groups

Preparation	Relative stiffness (Mean ± SD)	
	Prepared tooth	Restored tooth
Overlay	0.64±0.26	1.34±0.40
Onlay	0.90±0.68	1.14±0.11
U-Value	832.00	1070.50
P-Value	0.762ns	0.009*

*Significant ($p \leq 0.05$)/non-significant ($p > 0.05$).

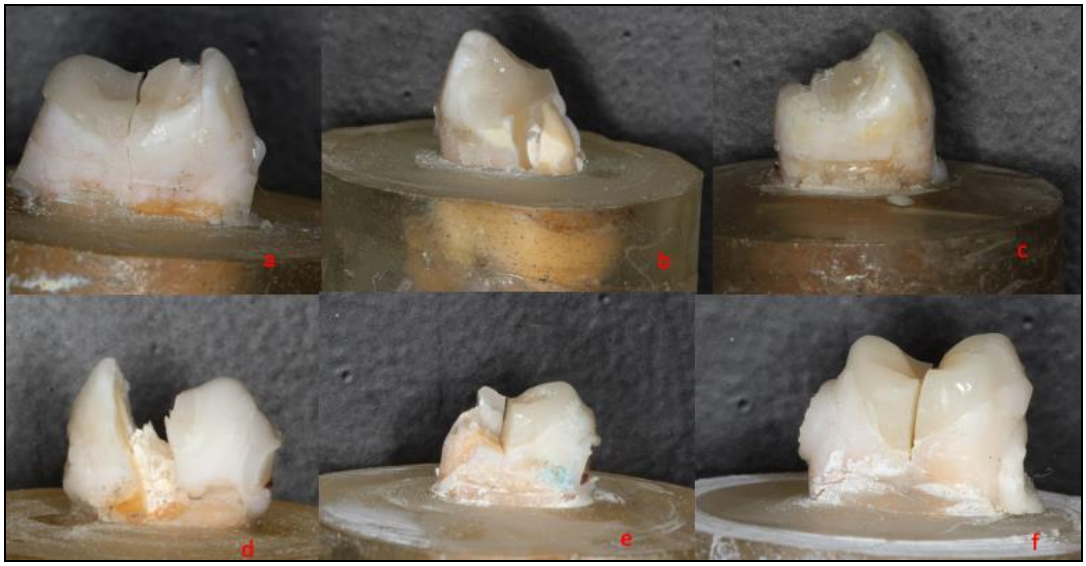

Fig 3: a, vertical crack at the central groove of both restoration and tooth (Group A), b, Palatal cusp splitting (Group A), c, Palatal ceramic chipping (Group A), d, Fracture and complete splitting of MOD area (Group B), e, Buccal cusp splitting (Group B), f, Vertical tooth fracture at the central groove (Group B)

5. Discussion

Today, biomimetic and minimal invasive concepts have good acceptance from both operators and patients, in addition to the immense progress in the CAD/CAM technology that facilitates the precision of the restoration. The wedging effect, together with the effect of the MOD cavity on the tooth stiffness and the root canal treatment, led to a unique tooth preparation, covering one cusp or all cusps and marginal ridges of the upper bicuspids. MOD design is a complex design, as in many cases, after removal of the decayed or fractured tooth structure, the marginal ridge becomes undermined and that's why MOD design is suitable for maxillary premolars [2, 12].

The null hypothesis was rejected regarding the relative stiffness results, as there is a statistically significant difference between the two groups within the relative stiffness of the restoration, as the restoration of the onlay group (1.03 for the buccal cusp and 1.14 for the palatal cusp) regained the stiffness to a nearly normal level compared to the sound teeth, while the overlay group (1.19 for the buccal cusp and 1.34 for the palatal cusp) regained the stiffness to a much higher level. These results were in accordance with Sorensen *et al*. (1984) [13], They showed that cuspal covering restorations perform better than intra-coronal inlay restorations in terms of protecting residual tooth tissue from the effects of recurrent occlusal loading and enhancing the clinical rate of success for posterior teeth.

These findings were in line with those of Seow *et al*. (2015) [5], who discovered that different designs of resin-bonded all-ceramic onlay replacements recovered tooth stiffness to varying degrees in endodontically treated maxillary premolars.

A large amount of the tooth stiffness was recovered as a result of the onlay with palatal cusp coverage restoration, with the restored tooth units having stiffness similar to that of a sound tooth. Other investigations have shown the same splinting effect, even though the typical onlay restorations made the endodontically treated maxillary premolar teeth stiffer than the level of the intact tooth [5, 14, 15]. Seow *et al*. (2015) [5] claimed that, with results of relative stiffness, the onlay with palatal coverage design could be an alternative treatment approach to endodontically treated upper bicuspids, with the added advantage of an intact buccal cusp for aesthetic and conservative purposes.

The null hypothesis was accepted regarding the fracture resistance results, as there was no statistically significant difference between the two groups in the fracture resistance tests and the P-Value was higher than 0.05. The mean fracture resistance of the two-preparation design falls between 1088.8 and 1230.1 N for both the onlay group and overlay group, respectively. This was in accordance with Chang *et al*. (2009) [16], from the clinical aspect, the usual biting force for the maxillary bicuspid region is 222-445 N. In contrast to Yildiz *et al.'s* (2013) [17] research on the fracture resistance of partially covered crowns made of machinable lithium disilicate ceramic with an occlusal thickness of 1.5 mm, which resulted in a fracture resistance of 2,356 +/- 677 N, this study's fracture resistance was lower.

This study found that partial coverage restoration, either with full cuspal coverage or with palatal cuspal coverage with loss of both marginal ridges, showed almost similar or even higher fracture resistance to premolars. Since the usual biting force for a maxillary bicuspid region is 222-445 N, while the occlusal force during clenching can reach 520-800 N.

6. Conclusion

From the results of this study, it can be concluded that root canal treatment and MOD tooth preparation design reduced the relative stiffness of the tooth structure. Both Partial coverage restorations designs (overlay and onlay) restored the relative stiffness of the tooth structure. Both Partial coverage restorations designs (overlay and onlay) could work as an alternative line of treatment for restoring endodontically treated maxillary premolars.

6.1 Acknowledgments: N/A.

6.2 Conflict of interest: N/A.

6.3 Financial Support: Self-fund.

6.4 Availability of data and materials

The corresponding author will provide the datasets used and/or analysed during the current work upon reasonable request.

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