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Fracture Resistance and Retention of CAD/CAM Endo-Crowns Using Different Preparation Designs

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KEYWORDS

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Fracture resistance,
Retention, ferrule

ABSTRACT

Purpose: to study the influence of different preparation designs on fracture resistance and retention of CAD/CAM endocrowns. **Materials and methods:** Forty human mandibular molars were selected to conduct the present study. All teeth were randomly divided into 2 groups (n=20 each) according to the preparation design of endocrown, Group (1): Endodontically treated teeth without ferrule (butt joint). Group (2): Endodontically treated teeth with 1mm ferrule. All prepared teeth were restored using IPS e-max CAD endocrowns. After cementation of endocrowns all specimens were subjected to thermal cycling in automated thermocycling machine in order to mimic the intra-oral condition. Then retention was measured using material testing machine, also fracture resistance was measured using material testing machine. The recorded data were collected, tabulated and statistically analyzed. **Results:** Endodontically treated molar with 1mm ferrule showed high fracture resistance and retention than endodontically treated molar without ferrule. **Conclusions:** All obtained fracture resistance and retention values lie within the clinically accepted ranges, endocrowns with 1mm ferrule have fracture resistance and retention higher than endocrowns without ferrule (butt joint).

INTRODUCTION

Endodontically treated teeth fractured more easily than vital teeth, as root canal treated teeth are brittle due to cavity preparation or caries which lead to loss of structural integrity , or due to decrease moisture content, planning to restore this teeth will be related to amount of residual structure and functional requirements[(1).] The strength of the

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tooth is directly associated with residual amount of dentin [2].

Decrease in amount of tooth structure following access preparation which conserve tooth structure, influences tooth rigidity by only 5%. The effect of following canal instrumentation and obturation lead only to a slight decrease in the resistance to fracture and ultimately have little effect on tooth biomechanics. In fact, the biggest decrease in tooth stiffness results from more preparation related to post preparation [3].

For a long time, post and core have been used as a basic material for final restoration of endodontically treated teeth with badly broken structure, but they need additional preparation in the root canal [4].

Vertical and deep root fractures have been associated with tapered cast posts and cores as they exhibit wedging effect within the root [2].

But fiber reinforced posts possess a number of advantages that include biocompatibility, high flexure and fatigue strength high resistance to corrosion modulus of elasticity like dentin of the teeth ,and form a single bonded (mono-block) complex within the root canal[5].

Although the fiber reinforced option in restoring pulpless badly broken down teeth proved a clinical success however the true revolution restoration of root canal treated teeth was with the development of adhesion and creation of effective dentin adhesives[6].

With this revolution the use of different post system has become the exception rather than the basic restoration, now a day preparation with minimal tissue loss and more conservative to tooth structure are now considered the gold standard for restoring root canal treated teeth [7]

Endocrown firmly follow this rational: the preparation involves a circular butt-joint margin and central retention cavity inside the pulp chamber and lacks intra-radicular anchorage constructing both the crown and core as a one unit, i.e., a monoblock[8].

The first promulgated study[9] on ceramic endocrown was published in 1995. It was described as the technique of ceramic monoblock fabrication for restoration of endodontically treated teeth. However, this restorative procedure was named later as "endocrown" in 1999 [10].

An endocrown is a single monoblock that contains the full crown and an intra-radicular anchorage that adapts into the "endo-preparation" [11] having macro-mechanical retention (obtained through fitting into the pulpal walls), and micro-retention (by using adhesive resin cement) [12].

Molars with short, calcified, severely curved and extra thin roots are specially indicated for endocrown restorations. Badly broken down teeth and reduced inter arch space also indicated for endocrown as there is no enough space for the ceramo-metal restoration or ceramic substructures [13].

There is no specific or defined design for endocrown preparation, some studies recommend endocrown preparation parameters to include; decrease occlusal height by 2 to 3 mm, 90° flat margins(no ferrule) , remove any sharpness in line angles, tapering internal axial walls by 6^0, flattened pulpal floor and supra-gingival enamel finish line when possible [14].

Many studies propose a 2 mm central cavity depth to increase resistance and retention features, [15, 16], while other studies highlighted the effect of the depth (shallow or deep depth) of this intra-radicular retentive feature on the marginal adaptation of the endocrown restorations [17, 18].

Long term success of fixed restorations is highly related to adequate marginal adaptation of the restoration. Exposed luting cement to the oral environment with increased marginal discrepancies, may lead to cement dissolution with subsequent micro-leakage. [19].

Therefore, the effect of altered endocrown's preparation on fracture resistance and retention of endocrown has to be thoroughly investigated.

The null hypothesis of the present study was that variation in margin design will have no influence on fracture resistance and retention of IPS e-max CAD endocrowns constructed on endodontically treated molar.

MATERIAL AND METHODS

Preparation of natural teeth:

Forty (N=40) human mandibular first molars have extracted with no cracks, fractures or caries and selected for current study. Each molar was mounted vertically in epoxy resin block using the dental surveyor. All molars were sectioned perpendicular to their long axis 2mm above CEJ. All sectioned molars were endodontically treated. Based on preparation design all root canal treated teeth (N=40) were separated into 2 groups (n=20 each) based on preparation design.

Grouping:

I. Group (1): Endodontically treated teeth without ferrule (butt joint).

II. Group (2): Endodontically treated teeth with 1mm ferrule

Pulp chamber of all sectioned teeth were treated with etchant gel for 20 sec, then washed with water spray then universal adhesive bonding agent was applied with a micro brush and cured for 30 sec, finally 3M flowable composite was applied and cured for 30 sec, to seal the orifice of the canal and to close any undercuts.

A special milling machine (Centroid milling machine) (Centroid CNC, Milling machine, USA) was used for standardized teeth preparations. The machine assembly incorporates a slow-speed hand-piece attached perpendicularly to the machine platform.

The endodontic access cavity was prepared with 10^{o} coronal divergence. The depth of the intra-radicular retention cavity was standardized for all specimens with 2mm. Cavity depths were measured from decapitation level using the digital caliper.

Fabrication of endocrowns:

Exocad dental system was used for construction of all specimens. All prepared teeth have a (3D) image, the prepared tooth was sprayed using a Telescan light reflecting powder from Vita Zahnfabrik, Germany, to obtain optical impression of the sample. Samples were scanned using Identica blue for scanning then the captured picture was saved, an automatic margin detector was used to detect margin of the preparation. Restoration design parameters were standardized for all specimens, with the aid of both exocad dental system and biogeneric copy option. The scanned prepared tooth was used to construct a 3D virtual endocrowns according to data gained during acquisition phase.

For the retention test the endocrowns were designed with lateral projection from mesial and distal to help in engaging the specimens during testing by material testing machine, (fig.1).

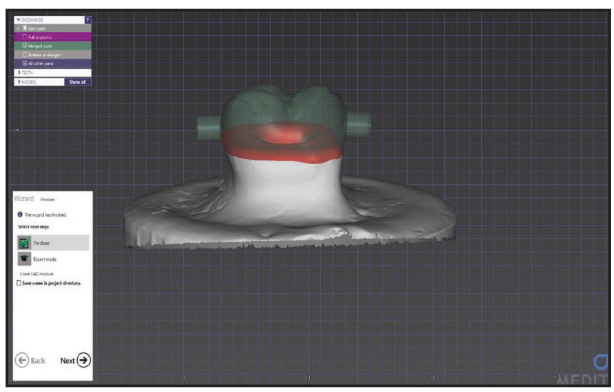

Figure (1) Virtual design by two latral projection

To start milling procedure the IPS Emax blocks were attached to the spindle arm of the milling chamber of Roland milling machine. This process was managed automatically with no interfering with diamond burs working organized with copious water from all directions, then for crystallization and glaze firing of all endocrowns programat Furnace was used. Ceramic endocrowns were bluish-gray in color which is their pre crystalized form after milling. Final strength and esthetic properties of this glass ceramic endocrowns obtained after crystallization process.

In firing process endocrowns were fixed by an object fix material and fired on their special firing tray as the manufacturer's instruction. The starting temperature was 403°c and increased by 90°c per minute up to 840°c and remain for 7 minutes to obtain final endocrown.

Each endocrown was then seated on its respective tooth and checked for complete seating using magnifying lens(x=15).

Cementation procedure

Restorations' internal surface treatment using Itena silane coupling agent and hydrofluoric acid (ITENA Clinical product, France), Tooth surface treatment using Scotchbond Universal Etchant and Single Bond Universal Adhesive(3M ESPE, St Paul, MN, USA), Bonding using RelyX Ultimate Clicker resin cement(3M ESPE, St Paul, MN, USA). Each sample was subjected to 3kg weight in a load applicator then adhesive resin was light cured for 20 seconds for all aspects of endocrown.

Thermal cycling

To resemble intra-oral condition, the cemented endocrowns were subjected to thermal cycling, in automated thermocycling machine, for 2000 cycle between 5- 55˚c with a dwell time 25 second.

Retention test

Retention test was performed on number of (20) endocrowns 10 from group by using materials testing machine, the block of the endocrown sample was tightened to the lower immovable part of the machine by screws, then the endocrown was suspended from the upper movable part of the testing machine by double orthodontic wire loop (0.7 mm) through two lateral projections made during milling. The endocrown was subjected to a slowly increasing tensile vertical load (1mm/min) until total dislodgment of the crown, the load needed to achieve dislodgment was documented in Newton.

Fracture resistance test

Fracture resistance test was performed on a number of (20) endocrown 10 from each group, by using material testing machine controlled by computer, all specimens were separately mounted on a machine and data were recorded using computer software. Specimen were tightened to the lower immovable part of the machine by screws. This test was done by using compressive action in occlusal direction using a metallic rod (5.8 mm diameter) attached to the upper movable part of the machine at cross-head speed of 1mm/min, the failure was demonstrated by an audible crack and confirmed by a sharp drop at load-deflection curve noted using computer software. The load required to fracture was recorded in Newton.

Statistical analysis

All data showed a parametric distribution and were compared between groups using independent t test. The connection between fracture resistance and retention was investigated using Pearson correlation test .The Pearson correlation coefficient is used to calculate the strength of a linear association between two variables. The level of significance was set at $P < 0.05$.

RESULTS

Fracture resistance

Higher mean failure load was documented for endocrowns with 1mm ferrule group (2), (3528.69N± 569.83) while endocrowns without ferrule group (1) recorded a mean failure load (2393.91±759.71) Independent t test showed that the difference between two groups was statistically significant (p=0.03), (fig.2).

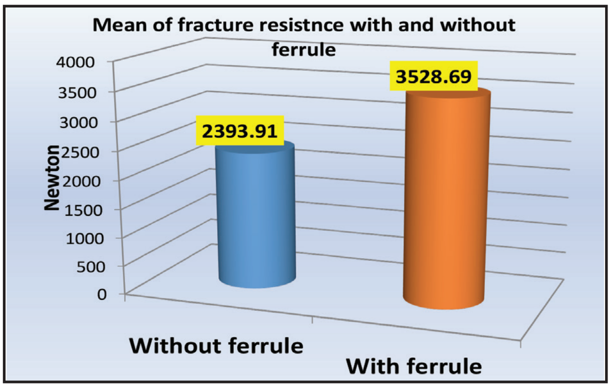

Figure (2) Column chart showing mean values of fracture resistance with and without ferrule

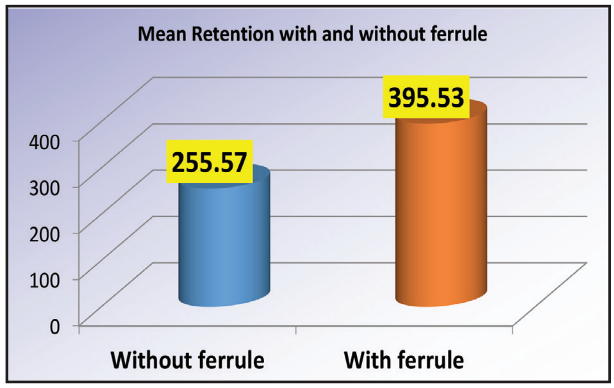

Figure (3) Column chart showing mean values of retention with and without ferrule

Fracture mode failure:

Samples were examined to determine the type of fracture occurred in this study visually using magnification lens (x=15) to define different fracture modes using Burke's classification. [42, 20, 21]

A- ***Class II failure:*** Less than half of the endocrowns fractured without fractured of the teeth. This type of failure did not occur in group (1), and occurred in 10% of group (2).

B- ***Class IV failure:*** More than half of endocrown fracture without fractured of the teeth. This type of failure occurred in 20% of both group, **C**-Class V failure: In this type of failure sever fracture occurred for both endocrowns and teeth .occurred in 80% of group (1), and 70% of group (2)

Retention:

The higher mean failure load was recorded for endocrowns with 1mm ferrule group (2), (395.53N±90.44) while endocrowns without ferrule group (1) recorded a mean failure load (255.57±11.20) Independent t test showed that the difference between groups was statistically significant (p=0.025), (fig.3).

Analysis of retention failure mood:

Samples were examined after debonding to determine the failure type occurred in this study using magnification lens (x=15).The type of failure was assigned according to the following: Adhesive failure: remnants of cement were detected only on the cemented surface of endocrowns, 40% of group (1) samples and 30% 0f group (2) samples showed adhesive failure Cohesive failure: Where remnants of the cement on both the endocrowns and internal wall of the tooth preparations. 60% of group (1) samples and 70% of group (2) samples showed cohesive failure.

DISCUSSION

With the introduction of improved dentin adhesives and new ceramic materials, bonded ceramic restoration are recognized as alternative to conventional crown which require macro-mechanically styled destructive preparation [22].

Therefore it is now possible to deviate from the classical preparation to what is called endo preparation technique and use endocrown in restoration of endodontically treated teeth [23]. Endocrown eliminate the need for posts and build up therefore they are less expensive, time saving and more practical [10]. Endocrowns were presented as a prosthetic treatment to restore root canal treated incisors [24], premolars [25] and molars [26, 27] with great tissue loss. The endo-core improves the bonding surface of restorations inside the root in addition to their macromechanical retention, decreasing their displacement from the root cavity under lateral stresses [28].

There had been no specific or defined preparation design for endocrown restorations, especially in terms of intracoronal cavity depth and marginal configuration. To give the optimal retention and resistance features, a 2 mm central retentive cavity depth was suggested. [29, 30] other studies highlighted the effect of the depth (shallow or deep cavities) of this central retentive feature on the marginal and internal adaptation of the endocrown. So we aimed to examine the effect of different marginal design on the fracture resistance and retention of endocrown as the prognosis of fixed restorations is directly related to its retention and fracture resistance [31].

To ensure standardization of the preparations molars were prepared using special milling machine[32]. Reduction of height of the prepared teeth to 2.0 mm, measured from the floor of the pulp chamber to the internal cavity margin as it demonstrated the highest fracture resistance [33].

By biogeneric option (Biogeneric copy mode in the exocad software used) standardization of e.max CAD restoration was done to have similar occlusal anatomy and also having the same height [34].

Although multiple CAD/CAM blocks are available for fabricating all ceramic crowns , IPS Emax CAD blocks was chosen because it has the advantage of long term clinical acceptability, good bonding features, short laboratory steps, favorable esthetics and lack for veneering porcelain need[35], in addition to high fracture load values for endocrowns fabricated from e.max CAD [36].

Indirect restorations are exposed to adverse conditions after cementation. Artificial in vitro aging can be performed to simulate in vivo conditions, namely temperature alterations and loading of the oral environment. Thermal cycling is among the aging methods that can be used. These procedures had been used to determine lifetime of restorative materials [37].

For retention test all endocrowns were constructed with two lateral projection (two bar) to facilitate removal of the specimens after cementation to give a means for removal of the endocrown in a testing machine by orthodontic wire from both side for equal distribution of force [38, 39]

Regarding the preparation design the results in showed that endocrowns with 1mm ferrule recorded a statistically higher mean fracture load than endocrown without ferrule. This result was agreement with studies [40, 41], who observed higher fracture loads of endocrown with 1mm ferrule than without ferrule.

This result can be explained by the fact that greater surface area for adhesive bonding for endocrown with 1mm ferrule over those without ferrule (94 mm^2 and 82 mm^2 respectively) increase fracture resistance of endocrown with ferrule than without ferrule, in addition to the presence of the ferrule effect. It has been reported that a ferrule with 1mm vertical height doubles the resistance to fracture than teeth restored without a ferrule and provide a greater amount of dentin for redistribution of force [42, 43].

Beside that considered ferrule of dentin and crown influences the fracture resistance. Teeth with an apical extended ferrule were fractured significantly at high load than teeth without (dentin and crown) ferrule. [44]

Another explanation may related to stress distribution, Tooth without ferrule showed greater stresses concentration than tooth with a ferrule. With a ferrule, stress was evenly distributed along coronal part and radicular part, without any stress concentration. Finite Element analysis confirmed a beneficial ferrule effect on stress distribution so affect mechanical behavior of the teeth and failure mode of restoration [45].

Moreover another study approved that endocrowns, comprising both the core and crown as one unit was suggested to provide a monoblock effect. When the monoblock system is subjected to occlusal loads, the whole system will deform uniformly and generated stresses will be distributed along the whole system decreasing the stresses transferred to the vulnerable tooth structure and increase fracture resistance [(46)], this suggestion is supported by study which informed that the stresses distributed over tooth structure and luting cement of conventional crown restoration were very high in relation to stress distributed in case of endocrowns restoration [(47)].

This was opposed by a study which report that regarding adhesive technique creating a ferrule might cause the loss of sound tooth structure and compromising bonding strength, because enamel is preferred to dentine for bonding. This opposed finding might be related to difference in methodology between the studies, this study preformed on premolars but my study performed on molars [(48)].

Regarding the retention the results in this study displayed that: endocrowns with 1mm ferrule reported statistically significant higher mean retention values than without ferrule.

This finding is probably related to the greater surface area for bonding in endocrowns with 1mm ferrule .it has been demonstrated that the increase in the surface area of resin cement coverage positively influence the retention of ceramic crowns. [(49)]

It may be also linked to the unique design of the endocrown with 1mm ferrule where it utilizes the pulp chamber for macro mechanical retention provided by pulpal walls as well as micro retention attained with the use of adhesive cementation, in addition it embraces the whole circumference of thee tooth extra coronally thus providing both external and internal retention. Furthermore the ferrule in endocrown preparations promotes the presence of four axial wall instead of two in other designs which positivity influence the retention [(50)].

On examination of the retention failure mode of the studied groups, it was found that no significant difference in mode of failure between two groups, most prominent failure mode was cohesive failure in the cement, where the remnant of cement was detected on both restoration and tooth. Which indicate that the bonding of cement to both tooth surface and restoration exceeds the inherent strength of the cement itself. The surface treatment of the tooth structure improved bonding with the cement and no adhesive failure occurred.

So, the null hypothesis that there would be no difference in fracture resistance and retention with variation in margin design was rejected. Endocrowns margin design affected both fracture resistance and retention.

CONCLUSIONS

Within the limitations of this study, the following conclusions can be drawn:

1. All obtained fracture resistance and retention values lie within the clinically accepted ranges.
2. Endocrown with 1mm ferrule marginal configuration has superior fracture resistance and retention than those without ferrule (butt joint) marginal configuration.

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