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Impact of Marginal Preparation Design on the Fracture Resistance of Endo-Crown All-Ceramic

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Abstract
Objectives: *The purpose of this in vitro study was to evaluate the fracture resistance of CAD/CAM zirconia reinforced lithium silicate glass ceramic (Vita suprinity) endo-crownin molars maxillary teeth.*
Materials and Methods: *A total 60 non carious, devitalized human maxillary molars free from cracks were restored with reinforced Vita suprinity used in this study.They were classified into 2main groups in each tooth, 30 specimens each according to the type of restoration and designs of preparation as following. Group* ***I: (n= 30)*** *endodontically treated upper molars with 2mm ferrule and deep chamfer finish line restored with Vita suprinity endo-crown. Group* ***II: (n=30)*** *endodontically treated upper molars restored with butt joint margin Vita suprinity endocrown. The teeth were prepared with a special milling machine and adhesively cemented with dual cure self-adhesive resin cement (Rely X U200).The samples were subjected to 3500 thermocycle. Then eachSpecimen was loadedto a universal testing machine. To failure at a crosshead speed of 0.5 mm / min. Mode of failure was also examined. Data were analyzed using one way analysis of variance (ANOVA) and Tukey's post hoc significance difference tests.*
Results:*There was no statistically significant difference between* ***Group I*** *and* ***Group II.*** *The highermean fracture resistance was detected among* ***Group I and Group II*** *(624.83 ± 126.04& 557.30±156.80), respectively.*
Conclusions:*Under the conditions of this study.There was no statistically significant difference between tested groups.*
Keywords: *Endocrown; Vita suprinity; CAD/CAM; Fracture resistance.*

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I. Introduction

The rehabilitation of severely damaged coronal hard tissue and endodontically treated teeth always poses a challenge to the dentists. Biological factors such as periodontal and/or endodontic prognosis, assessment of the individual caries risk, root anatomy and coronal remnant tissues must be considered before making a treatment decision. A tooth with a large loss of tooth structure generally requiresa post-and-core foundation to provide restoration retention.[1]

Posterior teeth following endodontic therapyareconsidered at a higher risk of fracture comparedto intact sound teeth as a consequence of lost toothstructure following the pathological processesand endodontic treatmentrequire adequate full-coverage restorations to minimize risk of fracture.[2] This biomechanicalalteration inflicts a negative impact on the long-termprognosis of restoration of these teeth. That'swhy when considering the restoration of devitalizedteeth, dental materials utilized should be able toreplace lost tooth substance, ensuring mechanical,functional and aesthetic performance in addition toperfect coronal seal.[3, 4]

Endocrown is a type of restoration consists of the entire core and crown as a single unit. It uses the available surface of the pulp chamber axial walls as macro-retentive resources and adhesive resin cement as a means of micromechanical retention.[5] Nowadays, ceramic endocrown restoration is considered an alternative treatment to post-and-core and conventional crown in endodontically treated molar teeth. The idea of restoring the endodontically treated premolars with endocrown restoration was also reported by many researchers.[6, 7]

One of the options to restore posterior endodontically treated teeth without posts is the restorative procedure introduced by Piassis in 1995, described as the "mono-block porcelain technique", later known as endo-crown. Pressed lithium disilicate ceramic, CAD-CAM feldspathic ceramic, CAD-CAM lithium disilicate ceramic and CAD-CAM resin nanoceramic are the materials and techniques more widely used for nowadays.[8]

The first study published on endocrown restorations (or adhesive endodontic restoration) was conducted by a studythat described the ceramic monoblock technique for teeth with extensive loss of coronal structure. [9] However, it was **Bindl and Mormann**[10]who named this restorative procedure “endo-crown” **in 1999.** The endo-crown is a total porcelain crown fixed to a root treated posterior tooth, and anchored to the internal portion of the pulp chamber and to the cavity margins, thus obtaining macro-mechanical retention (provided by the pulpal walls), in addition to micro-retention (by using adhesive cementation). [11]

Minimally invasive preparation to preserve a maximum amount of tooth structure is considered the gold standard for restoring teeth. Endo-crowns, with a decay-orientated design concepthave become increasingly popular because of their advantages in preserving the maximum tooth tissue, reducing the need for auxiliary retentive geometry and saving treatment time and expense as fewer operation steps are involved. Moreover, the development of dental CAD/CAM systems provides a novel means of chair-side design and automatic fabrication of all ceramic restorations, especially the ceramic endo-crown that constructs both the crown and the core as a single unit several in vitro studies have reported that molars with ceramic endo-crown showed better fracture resistance than those with conventional post-core supported ceramic crowns.[12]

Endo-crowns were revealed to fail more when fixed to premolars, probably due to their smaller adhesion area and greater crown height compared to molars. In addition, premolars receive more horizontally (non-axial) directed forces than molars, which may also influence fracture resistance.[11] Strong bonding between the indirect restoration and tooth structure increases the durability and longevity of the prosthesis.[13]

A wide collection of ceramic materials had beenavailable for CAD/CAM technology, ranging fromfeldspathic ceramics and leucite containing glassceramics to high-strength lithium disilicate glassceramics and zirconium oxide.[14]

Reinforced, acid etchable dental ceramics havebeen the materials of choice for the fabrication ofendo-crowns, because they guarantee the mechanicalstrength needed to withstand the occlusal forcesexerted on the tooth, as well as the bond strength ofthe restoration to the cavity walls.[12, 15] A monolithicrestoration (also known as a full contour restoration)is one that is manufactured from a single material forthe full anatomic replacement of lost tooth structure.Additional staining, followed by glaze fring, maybe performed to enhance the appearance of therestoration. For decades, monolithic restorationhas been the standard for inlay and partial crownrestorations manufactured by both pressing andcomputer-aided design and manufacturing (CAD/CAM) techniques. A limited selection of monolithicmaterials is now available for dental crown and bridge restorations.[14]

Recently introduced ceramic Vita Suprinity (Vita, Zahnfabrik, Bad Sackingen, Germany) is a lithium silicate ceramic enriched with zirconia (approx.10%). This new glass ceramic features a special fine grained and homogenous structure, which guarantees excellent material quality, consistent high load capacity and excellent translucency. The major problems related to veneered zirconia based restoration as well as veneered lithium disilicate based restoration was chipping or delamination of this weak veneering layer when subjected to functional loads (flexural strength 30 to 100MPa).[16] Up to our knowledge no current studies compared the fracture resistance of endodontically treated premolars and molars prepared either with ferrule or butt joint design and restored with endo-crown fabricated with zirconia reinforced glass-ceramic.

The present study therefore aimed at comparing the fracture resistance of vita suprinity endocrowns with two designs (conventional endocrown butt joint and ferrule endocrown) in molar teeth.

II. Material And Methods

Preparation of tooth samples

The materials used in this study are listed in Table (1). Sixty (n=60) maxillary molars withcompleted roots, free of cracks or fracture werecollected cleaned and stored in0.9% sterile saline solution to avoid dryness. To standardizethe size of the selected teeth a digital caliper (S235,Sylvac, Switzerland), was used to measure thebucco lingual and mesio-distal dimensions of eachmolar at the level of the cemento-enamel junction.

Teeth were sectioned 2 mm above the cementoenamel junction (CEJ) perpendicular to the long axis of the tooth by using a special milling machine (Centroid CNC, Milling machine, USA). Each tooth was individually embedded vertically in epoxy resin using centralizing device. All teeth were endodontically prepared using rotary files (Dentsply Maillefer, Switzerland) then filled with gutta percha (Dentsply Maillefer, Switzerland) using lateral compaction technique.

All endodontically treated teeth (n=60) wererandomly divided into 2 groups. Each group was subdivided into two subgroups; group with butt joint preparation (N=30) and group with ferrule preparation design (n=30)

Endo-crown Preparation with butt joint:

After coronal sectioning to prepare a circular butt margin, gutta percha was removed till canals entrance with no more drilling inside the canals, a thin layer of flowable composite material (Filtek Z350, 3M ESPE Dental products, St. Paul, USA) was bonded to seal the canal entrance and to enhance the bonding of the ceramics endocrowns constructed in later stage.A special milling machine (Centroid CNC,Milling machine, USA) was used for standardized teeth preparations with 10^o coronal divergence, the depth of the central retention cavity measured 3.5±0.5mm from decapitation level.Extracoronally, the remaining vertical portion of thecrown was prepared with diamond stone (Dentsply Maillefer, Switzerland). The preparation included a 1 mm wide, circumferential 90o shoulder margin with rounded internal line angles, located 2 mm above the cementoenamel junction leaving a 2mm ferrule. The external convergence angle was adjusted at 10^o. The remaining thickness of dentin walls (2±0.5 mm) was measured by digital caliper.

Endo-crown with 2mm ferrule:

Gutta percha was removed till the canal orifice 1mm with no more drilling inside the canals. A thin layer of flowable composite material was bonded to seal the canals orifice and to enhance the bonding to the vita suprinity endocrown constructed in the later stage. Prepare the samples of this group. The endodontic access cavity was prepared to eliminate undercut with a 10 coronal divergence. Extracoronally, the remaining vertical portion of the crown was prepared with a circumferential deep chamfer margin 1mm wide with rounded internal angles located on sound tooth structure junction leaving 2mm ferrule and with 10 convergence angle. The depth of pulp chamber was 3.5±0.5mm from coronal tooth structure to the flowable composite applied to seal the canals orifices and pulp floor.

Laboratory procedures

To obtain a three-dimensional image for each prepared tooth on the computer screen of the (Ceramill Motion 2 (5x) Amann Girrbach Germany); the prepared tooth was sprayed with anti-reflection scan powder spray(Digi scan-Spray Yeti Dentalprodukte Germany) and scanned using the optical scanner (dental wings 3series GmbH, Germany). The restorations (ferrule endocrowns and conventional endocrowns) were designed and fabricated with CAD/CAM inLab machine using Vita suprinity CAD/CAM blocks (Ivocalr Vivadent, Germany).

After restoration milling and adaptation verification, two coats of spray glazewere applied with crystallization firing accomplished following manufacturer recommendations in a dental laboratory ceramic furnace (Vita furnace; Germany).

Cementation procedures:

Surface treatment of the ceramic endocrown:

The internal fitting surfaces of each endocrown were etched using 8% hydrofluoric acid etching gel for 20 seconds according to manufactures instructions. The etched surfaces were rinsed using water spray for 60 seconds, dried for 30 seconds with Oil-free compressed air was used to dry. A ceramic primer containing silane coupling agent was applied using a micro-brush to the etched fitting surfaces for each endocrowns allowed to dry for 60 seconds then leave to dry.

Surface treatment of the prepared natural tooth:

Surface treatment of the prepared natural tooth: Prepared tooth surfaces were etched with 37% phosphoric acid–etching gel (ETCH-37 w/BAC, Bisco Inc, USA) for 15 seconds, rinsed for 20 seconds, and dried with oil-free air for another 5 seconds. Two separate coats of all bond (Universal ALL-BOND UNIVERSAL, Bisco Inc, USA), were applied to the preparation with a microbrush with no light curing between the coats. Excess solvent was then dried with oil-free air for 3 seconds, then light cured for 20 seconds.

Application of RelyX U200 cement:

The dual cure resin cement Rylex U200 (Rylex U200, 3M, Germany) was applied with plastic instrument on the prepared surface of teeth**.** Then each endocrown was bonded to its corresponding tooth with finger pressure,then light activated at each surface for 20 seconds excess cement was removed immediately with a cotton pellet. Then transferred immediately to the customized loading device**.** It was used to apply a constant seating load of 3kg[17] parallel to the long axis of each restoration to prevent rebounding of the restoration during cementation until setting of the cement Excess cement on the margins was removed carefully with cotton pellet**.**Specimens were stored in distilled water at 37^oC for one week to allow for bonded interface maturation.[18]

Thermal cycling:
All samples were subjected to a thermocycling procedure in automated thermocycling machine. Samples were thermocycled for 3500 cycle, [19]between 5°C-55°C, with a dwell time25seconds.

Testingprocedures:
Fracture Strength (Fracture load) determination:
Each sample was individually mounted to the lower compartment of a universal testing machineby tightening screws (LRX-Plus, Lloyd Instruments, UK) and subjected to a static increasing compressive load (1mm/ min) applied vertically to the occlusal surface until fracture. FractureloadswererecordedinNewton.

Statistical analysis
Data were fed to the computer and analyzed using IBM SPSS(Statistical Package for social Science) software package version 20.0.

III. Results:

One way ANOVA showed no statistically significant differences between studied groups showed in molars teeth **Group I** and **Group II** from each other (p=0.3).The mean fracture resistance maximum load was detected among **Group I** and least for **Group II** (624.83 ± 126.04 & 557.30±156.80, respectively).

IV. Discussion:

The restoration of endodontically treated teeth with extensive tooth loss and minimal macro retentive feature is of particular clinical interest.[20] One of the major causes of failure of endodontically treated teeth is fracture, which is related to the amount of healthy dentine remaining. So one of the major objectives of endodontic therapy and subsequent restorative procedures is the maximum conservation of internal dentine.[21]

Endocrown restorations seemed to eliminate the need for posts andbuildups. For several factors including the differences inconfiguration/design, thickness, and elastic moduli, less expansive,time saving and more practical that endo-crown have compared toconventional systems.[22]

By avoiding the ferrule, which is typically found in conventionalcrowns and can be described as a 'bracing mechanism' of therestoration around the cervical tooth structure may cause the loss ofsound enamel and dentin tissues that would be important for proper bonding of the restoration. In addition it's reduce the need for macro retentive geometry, and provide a more esthetic result beingconstructed from ceramic.[23]

In this study, human teeth were used instead of bovine, metal orplastic teeth because of their bonding characteristics,thermalconductivity, modulus of elasticity and strength that closer to clinicalsituation.[24]Attention was paid to the selection of teeth withcomparable sizes, in which the teeth were selected to be of approximatesimilarity in size and shape with 10% maximum deviation from thedetermined mean to eliminate any extreme variation for the maxillarypremolars and molars.

A centralizing device was used to embed theteeth vertically in the center of the epoxy resin blocks to ensure theposition standardization. Teeth were embedded in epoxy resin 2 mmbelow the cemento enamel junction to mimic the position if the root inthe bone. Epoxy resin was used as it modulus of elasticity (12 GPa) resemble that of the human bone (18 GPa).[25] All teeth weredecapitated perpendicular to the long axis 2 mm coronal to theproximal CEJ in order to simulate the compromised condition ofseverely damage endodontically treated teeth molars.[25, 26]Teeth were prepared according to clinically established preparation criteria for all ceramic endocrowns using a special milling machine toensure standardization of the preparation.[27, 28]The development ofCeramill CAD-CAM systems and software offers several advantages inclinical practice.

Regarding to the preparation design, the result obtained in this study showed that vita suprinity endocrown with ferrule(624.83±126.04N) endocrown with butt joint in molars (557.30±156.80N). On other hands, **Schmidlin et al.**[29] indicated the presence of ferrule effect witch distribute the stresses of the endodontically treated tooth.

This results were in agreement with **Abdel-aziz and Abo-almagd 2015**[2]that was found that group (fiber post and conventional crown with ferrule) recorded statistically significant highest mean value (1262.71± 277.8 N) followed by group (endocrown with ferrule) (1139.7 ± 277.94 N) then group (endocrown without ferrule) (725.73 ± 137.89 N) they concluded that glass fiber post then endocrown with ferrule all ceramic crown with ferrule increases the fracture resistance more than that without ferrule.The results of present study showed that group (fiber post with ferrule) recorded the highest fracture resistance and there was no significant difference with group endocrown this result was agreement with the study of

This result was opposed with by **Lin et al.**[30]Observed thefavorable performance of endocrown restorations in premolars overconventional crown by using the finite element method and **Chang et al.**[31]They foundthat the endocrown and conventional crown with post and corerestorations for endodontically treated premolars did not significantly differ from each other. They explained that the endocrown restorationsrecorded comparable stress values because endocrown include boththe crown and core as a single unit which decrease the effect of multiple interfaces that found in conventional crown. As well,thickening of the ceramic occlusal portion compared to theconventional crown.

Benli M and Gokcen R B.[32]Mandibular first molar used for crown restorations reported that fracture strength values were statistically significantly influenced by material thickness (p<.001)but not material type. Strength values were significantly higher for 1.5 mm thickness may be a good choice for crown restoration.

Taha,Sebastian et al.[33]Fracture resistance of endodontically treated teeth group Group S3.5 showed the highest mean fracture load value (1.27±0.31 kN). Endocrowns with shoulder finish line had significantly higher mean fracture resistance values than endocrowns with butt margin ($p < 0.05$). However, the results were not statistically significant regarding the restoration thickness. Evaluation of the fracture modes revealed no statistically significant difference between the modes of failure of tested groups. They concluded that for the restoration of endodontically treated teeth, adding a short axial wall and shoulder finish line can increase the fracture resistance.

Michael,Nicholas.[34]Under the conditions of this study mandibular molars,no difference in failure resistance among the three groups; however, failure load results identified that the endocrown preparations without ferrule had significantly lower fracture load resistance. Ferrule containing endocrown preparations demonstrated significantly greater failure loads than standard endocrown restoration.

This was opposed by **Biacchi et al.**[13]Who reported that with the adhesive technique creating a sufficient ferrule might cause loss of tooth structure and result in compromised bonding strength, because enamel is preferred to dentine bonding, this contradictory finding might be related to the difference in the material and methodology between studies. Where Biacchi et al. used Rely X cement to perform study.

This results were in agreement with **Al-shibri and Elguindy.**[35]That was found that group (fiber post and conventional crown with ferrule) recorded statistically significant highest mean value (1301.34 N) then group (GE) (725.73 N).

This result was opposed with by **Khemakhem,et al**[36]Who reported that no statistically significant difference in failure load among the four tested subgroups (at $P< 0.05$). Endocrowns recorded statistically significant mean higher fracture load values (1729.91N±407.9) compared to post retained crowns, (1435.84±405.2).they Concluded thatlithium disilicate based endocrown restorations increase the fracture resistance of endodontically treated molars compared to conventional crowns associated with glass fiber posts and resin composite filling cores.

Duvall et al.[37]The 2- and 4-mm chamber extension groups demonstrated the highest fracture resistance stress, with the 3-mm group similar to the 2-mm group. The 3- and 4-mm chamber extension group specimens demonstrated nearly universal catastrophic tooth fracture, whereas half the 2-mm chamber extension group displayed non restorable root fractures.Extension group specimens demonstrated nearly universal catastrophic tooth fracture, whereas half the 2-mm chamber extension group displayed non restorable root fractures. They Concluded that under the conditions of this study, mandibular molars restored with the endocrown technique with 2- and 4-mm pulp chamber extensions displayed greater tooth fracture resistance force as well as stress.

Hamza T, andSheriff, R[38]Vita suprinity crowns showed the highest statistically significant (p<0.05) mean fracture resistance values (1742.9±102.7 N) followed by IPS e.max cad (1565.2±89.7 N) bilayered zirconia based crowns the lowest significantly mean value (1267.8 ± 86.1 N). They concluded that vita suprinity and IPS e.max cad have better fracture resistance than bilayered zirconia.

V. Conclusion

Within the limitations of this in-vitro study, it was concluded that;
1) Zirconia-reinforced lithium silicate ceramics (Vita suprinity) showed the highest values of fracture resistance.
2)Further investigations are needed to test the reliability of using the unfired as milled version of zirconia-reinforced lithium silicate ceramic material as endocrown restorations to be polished and used immediately after milling; still the values of fracture resistance in this study are considered promising.
3)Endocrowns can be used safely in terms of fracture strength asboth have values which exceed the physiologic requirements.
4)Higher fracture strength values can be obtained with glass ceramic endocrowns if good bondingis guaranteed.
5)All fracture resistance loads obtained were far beyond themaximum masticatory forces, which can with stand the maximumintraoral masticatory forces in the maxillary molar region.
6) There is no difference between endocrown with ferrule and butt joint in this study.

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TABLES:

Table (1): Materials used in this study.

Patch#	**Material**	**Composition**	**Manufacturer**
60340	Vita suprinity	ZrO2 (zirconium dioxide) 8 - 12 % SiO2 (silicon dioxide) 56 - 64 % Li2O(lithium oxide)15 - 21 % La_2O_3(lanthanum oxide 0.1%) pigments 1%, Various > 10 %	Vita-Zahnfabrik. Germany
671502	RelyX Unicem 200	Automix contains bi-functional (meth) acrylate. The proportion of inorganic fillers is about 43% by volume; the grain size (D 90%) is about 12.5 um. The mixing ratio, based on volume, is 1 part base paste: 1 part catalyst.	3M Deutschland, Germany
4178-17ppxs	Hydrofluoric acid and silane	Etch:hydrofluric8%,water90%xantan1>5% silane: ethyl alcohol 97%, glycidoxyrophpyltrimeth3%	Paris. France

Table (2): The P-value (one-way ANOVA) for the mean failure loads (N) of the four tested-subgroups.

	Molar teeth (n=30)			**One Way ANOVA Test**	**P-value**
Fracture resistance		Endocrown with ferrule N=10	Endocrown with butt N=10		
Maximum load /N Mean±SD		624.83±126.04	557.30±156.80	F=32.00	<0.001*#

F: One Way ANOVA test

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