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ORIGINAL RESEARCH

FRACTURE RESISTANCE OF ENDOCROWNS WITH DIFFERENT CAVITY DESIGN AND BASE MATERIALS IN MOLARS: AN IN VITRO STUDY

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ABSTRACT

Objective: The present study tested the fracture strength and fracture mode of endocrowns of mandibular molars with conventional and anatomical preparations using EverX Posterior, Smart Dentin Replacement® Plus Bulk Fill Composite, and ceramic extension (central retainer).

Materials and Methods: Sixty intact recently extracted human mandibular third molars were en- dodontically treated and were assigned to two main groups according to the preparation design: standard (conventional) and modified. The samples in each group were further divided into three subgroups (n=10) according to the material used as the base: fiber-reinforced composite (EverX Posterior), bulkfill flow-able composite (SDR), and ceramic extension. Thermocycling (between 5°C and 55°C/1500 cycles) was performed on all specimens. Following which fracture load was tested using a universal testing machine and the amount of maximum load on failure (Newton) was recorded. Failure types were examined using a stereomicroscope and categorized. Data were subjected to one-way ANOVA followed by Tukey's post-hoc test for determination of statistically significant differences ($p < 0.05$).

Results: The significant test results showcased Conventional preparation methods having a higher mean than its modified counterparts. Also, significantly between the material used Ever X poste- rior was the toughest with an average fracture resistance of 2913N, followed by SDR being tougher than Ceramic. For the failure modes the most common failure type was V. Between the two prep- aration methods, conventional samples had a significantly higher chance of resulting in a Type I failure.

Conclusion: Conventional cavity preparation configuration produces a higher mean fracture re- sistance value it was, however, significantly higher in comparison to the modified preparations. EverX Posterior was the most resistant base close to ceramic and resistant compared with SDR. Regarding the failure modes, conventional preparations presented a higher risk of Type I failures. These results demonstrate that preparation design and material selection are each of primary im- portance in maximizing fracture resistance and determining the characteristic of failure in restora- tions.

***Keywords*:** Fracture Resistance, Endocrown Design, EverX Posterior, SDR® Plus.

INTRODUCTION

Endodontically treated teeth (ETTs) are challenging to restore due to the loss of tooth structure with reduced mechanical resistance, and restorative techniques that provide strength, esthetics and durability are essential[1]. Post-and-cores, traditional crowns, while being in wide use, frequently necessitate invasive preparation, which may weaken the tooth even more[2]. Endocrowns have recently been introduced as a conservative option, particularly in posterior teeth with a significant coronal destruction[3,4]. These bonded monolithic restorations fuse to the pulp chamber giving re- tention and resistance in addition to preserving tooth structure that is left behind[5]. lithium disilicate is a preferred material owing to its high flexural strength (~350 MPa), esthetic qualities, and good bonding[6,7]. Endocrown designs (modified anatomical form) seem to have potential to increase the biomechanical behavior when compared to the conventional butt-joint one, modifying stress dis- tribution[2,8,9]. Also, dentin-like base materials, such as fiber-reinforced composites such as EverX Posterior, may serve to improve fracture resistance[10]**.** Only few have directly compared endo- crowns with different preparation designs (conventional vs. modified anatomical) and base mate- rials, and it remains unclear if these combinations are more or less advantageous under functional loading. The present study aims to elucidate these uncertainties by considering the influence of the design and core material type on the mechanical behavior and failure modes of endocrown poste- rior restorations.

MATERIAL AND METHODS

This experimental study involved 60 human permanent mandibular third molars, which were drawn from a pool of 600 newly extracted teeth from local oral and maxillofacial clinics. Extrac- tion of teeth was for routine clinical indications and a stereo-microscope (20×) was used to verify the presence of fully formed apices and absence of dental caries, restorations, previous endodontic treatment, and visible traces of fractures. Teeth that approximately matched in size within 10% deviation (in mesiodistal or buccolingual dimension at the CEJ) were included. These included only molars that, based on visual inspection, had cruciform sulci and four cusps, such as mandib- ular second molars. This morphology was selected because of its simplicity, reproducible-ness, and uniform distribution of axial loads[11]. Teeth were cleaned ultrasonically and put in 0.1% thymol solution.

All teeth were instrumented with ProTaper Next rotary system (X2 for mesial canals, X3 for distal canal) and filled as a single cone using AH Plus sealer [12,13]. After filling, the teeth were stored at 37˚C in 100% relative humidity for 7 days The teeth were fixed into pre-fabricated metal tubes (diameter 25 mm and height 20 mm). The molds were filled with acrylic resin and the mixing was made according to the manufacturer. The roots were attached to the acrylic resin, and the resin margin was placed 2 mm below the CEJ to simulate the level of bone[7].

Then the specimens were randomly divided into two preparation design groups: conventional and modified (anatomical), and into three subgroups of base materials: (a) EverX Posterior (short fiber reinforcement composite), (b) SDR ® Plus (Bulk Fill Composite), and (c) ceramic base (central retainer). Preparation was carried out with a surveyor-mounted handpiece with 4.5× magnification.

In conventional preparations, a 2-mm occlusal reduction with a diamond wheel bur under water cooling was made, delivering a butt joint line of 2.5±0.5 mm. Occlusal reduction was performed with 2.0mm depth orientation grooves from the buccal and lingual grooves toward the central pit made using a diamond-coated depth marker coarse grit bur with a rounded and angled stopping surface. Diamond wheel bur was applied along tooth length, parallel to the occlusal plane, to con- firm correct reduced alignment and to create a flattened but joint surface. Pulp chamber cavity preparation, the pulp chamber was prepared with an 8° taper using a flat-ended tapered bur[14].

An- atomical designs, 2 mm occlusal reduction was per- formed along the natural fissures and cusp inclines with a flat-ended diamond bur. A circumferential bevel 1 mm in length and of 45° was made to obtain a dome-shaped crown. Pulp chamber cavity was pre-pared with 8° taper by a flat ended taper bur[15,16]. All cavities were polished to obtain smooth surfaces.

Following cavity design preparation, the pulp chamber was etched with 37% phosphoric acid, and G-Premio Bond was applied and light-cured. In EverX and SDR groups, one layer of everX Flow was applied at the base of the cavity, light cured for 20 seconds for standardization with a calibrated LED unit[17].

In EverX Posterior Group, a thin layer of everX Flow (GC, Tokyo, Ja-pan) was placed at the cavity floor and light-cured. The procedure was completed by the addition of the EverX Posterior composite in 3mm increments placed one on top of the other from each surface and each layer was then condensed by means of a plastic instrument and light-cured for 20 s (10 s soft mode, 10 s hard mode)[10].

The thickness of the composites was measured to match the 3-mm (Figure 1). SDR groups after application of everX Flow in the cavity floor, a 3 mm bulk increment of SDR composite was flowed in the pulp chamber. A soft pulse and hard pulse 40 s light-curing was ap- plied to ensure its total polymerization and adaptation[18]. The gross thickness of the final coat was confirmed to be consistent with a thickness of 3 mm (Figure 2). For the ceramic base extension groups, the endocrowns were completely made of lithium disilicate ceramic, and reached the pulp chamber under there was no base material (Figure 3).

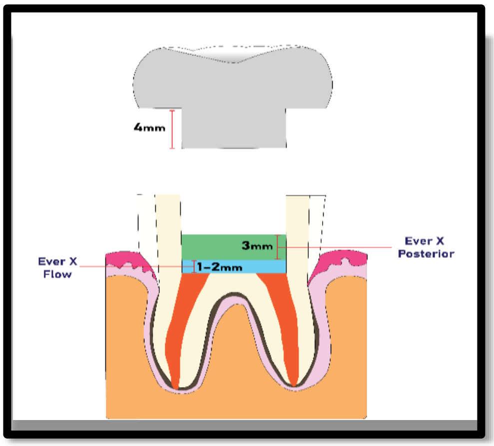

Figure 1. Illustration of Endocrown specimen groups restored with everX posterior base material.

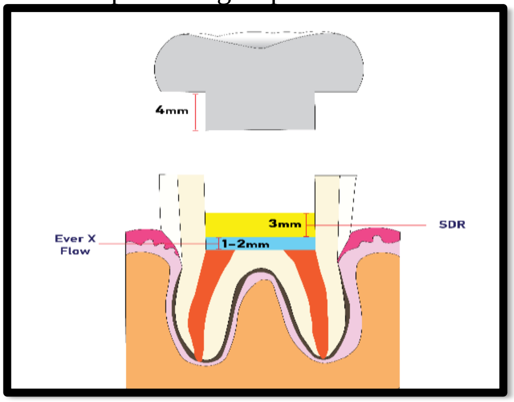

Figure 2. Illustrati on of endocrown specimen groups restored with SDR as base material

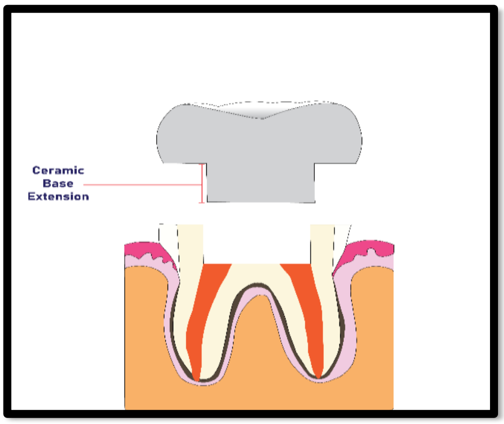

Figure 3. Illustration of endocrown specimen groups restored with ceramic base extension (central retainer).

All the teeth were then digitized with TRIOS 5, and restorations were designed with Exocad on the basis of the model of a mandibular second molar[19,20]. Endocrowns were milled from blocks of IPS e.max CAD LT A1 in the Cerec MCXL, then sintered at 840°C, polished, and glazed. Fit was examined un-der magnification and any ill fits were excluded.

Following that All restoration Intaglio surface were cleansed, etched with 5%H F Acid and Si- lanized[21]. Air-abrasion and etching of tooth surfaces. Subsequently, each restoration was loaded axially at 5 kg force for 5 minutes by the dental surveyor through a metal rod placed on the occlusal surface with RelyX U200 cement, and the margins were polished[6,7]. Samples were kept in water at 37 °C for one week.

All were subjected to 1,500 repetitive thermal cycles (5°C to 55°C) to simulate aging[19]. After thermocycling, the samples were tested for fracture resistance, in a universal testing ma-chine (TERCO, MT 3037, Sweden). The specimens were fixed into a jig and then axially loaded in the long axis direction of the tooth. A 2.5 kg weight compressed down onto a 6mm stainless sphere, placed on the central fossae of the occlusal surface. The loading stylus was repositioned to contact their facial and lingual cusp planes and tested at a cross-head speed of 0.5 mm/min. Loading con- tinued until plastic deformation or sudden failure took place. The fracture loads in Newton (N) and then specimens were observed after the fracture using 20x magnification and categorized as Type I (cohesive), Type II (adhesive), Type III (mixed), Type IV (above CEJ) or Type V (below CEJ)[7]. The types I through III were restorable, type IV acceptable, and type V non-restorable[22].

Further, the data were subjected to one-way ANOVA to assess the differences among six groups for fracture resistance. Tukey's Honest Significant Differences test was employed to identify which groups were significantly different. Also, all the pair-wise comparisons for normal distribution, and equal variances, were made by the Dwass-Steel-Critchlow-Fligner (DSCF) test as a nonpara- metric alternative. Statistical The analysis and graphs were performed using Statistical Package for Social Sciences software.

RESULTS

In Table (1) Conventional endocrown designs exhibited higher resistance to fracture than compar- ison with the modified designs regardless of the materials used. EverX Posterior statistically per- formed better than SDR and ceramic bases. The only significant differences were observed in the conventional groups between EverX and SDR, and between SDR and ceramic ($p < 0.05$), showing that the design and material selection were fundamental to the success of the endocrown.

Table 1: *Fracture resistance by material and design (N), with material based pairwise comparison*

Design	*Base Material*	*Mean*	*Standard Deviation*	*Base Material compari- son*	*P-value*
Conventional	*EverX Posterior (n=10)*	*2913*	*1135*	***EverX posterior > SDR***	***0.0049***
	SDR (n=10)	*2186*	*875*	***Ever X posterior > Ceramic***	***0.518***
	Ceramic base extension (n=10)	*1782*	*800*	***SDR > Ceramic base extension***	***0.0041***
Modified	*EverX posterior (n=10)*	*2123*	*1085*	***Ever X Posterior > SDR***	***0.812***
	SDR (n=10)	*1990*	*1165*	***Ever X Posterior> Ceramic base extension***	***0.317***
	Ceramic base extension (n=10)	*1895*	*727*	***SDR > Ceramic base extension***	***0.286***

Notes: One way ANOVA (SPSS); Pair wise comparison set at $p < 0.05$; post hoc applied where sig- nificant.

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Table (2) EverX Posterior, presented statistically superior results in the conventional format com- pared to the modified one. SDR showed a pattern in the same direction, but the difference was not statistically significant. Ceramic base extension increased a little in the modified, but not with any relevance.

Table 2: Preparation design-based Fracture resistance (N), with preparation design based pairwise comparison.

Design	Mean (N=30)	Standard Deviation	Base Material	Pairwise Comparison	p-value
Conventional	2159	800	Ever X posterior	Conventional > Modified	0.0281
			SDR	Conventional > Modified	0.0863
Modified	2072.2	1084.8	Ceramic base extension	Modified > Conventional	0.864

Notes: DSCF test ($p < 0.05$); post hoc applied where significant.

Tables (3) Posterior EverX posterior endocrowns showed significantly higher fracture resistance in the conventional design than in the modified design (p = 0.0281). Non-significant trend in SDR was observed in favor of the conventional design, but the ceramic base extensions did not differ between the two designs. These findings substantiate the advantage of conventional preparations for fiber reinforced composites and indicate that design alterations may not benefit all materials equally.

Table 3: *Fracture resistance by material (N), with preparation design pairwise comparison*

Base Material	*Mean*	*Standard Deviation*	*Pairwise Comparison*	*p-value*
EverX posterior N=20	*2913*	*1135*	*Conventional > Modified*	*0.0281*
SDR N=20	*2038*	*875*	*Conventional > Modified*	*0.0863*
Ceramic base extension N=20	*1838*	*800*	*Modified >Conventional*	*0.864*

Notes: One way ANOVA (SPSS); Pair wise comparison set at $p < 0.05$; post hoc applied where significant.

Table (4), Conventional designs failed with a more favorable (Type I) failure mode, especially for EverX posterior and SDR, whereas the modified designs, especially for ceramic and EverX posterior, exhibited a more catastrophic (Type V) fracture. Differences of failure mode were observed to be remarkable for EverX posterior and SDR between designs.

Table 4: Percentage of Failure mode in six tested groups.

Design Preparation	Material	Failure Type (%)					
		TYPE I	TYPE II	TYPE III	TYPE IV	TYPE V	P-value
Conventional	EverX posterior	7 (70)	0	0	3 (30)	0	0.0013
	SDR	7 (70)	0	0	0	3 (30)	0.96
	Ceramic base extension	7 (70)	0	0	0	3 (30)	0.96
Modified	EverX posterior	1 (10)	0	0	0	9 (90)	0.1
	SDR	5 (50)	0	0	0	5 (50)	0.0039
	Ceramic base extension	0	0	0	0	10 (100)	0.98

Notes: The Fishers exact test was performed for the comparison of type I and V.

DISCUSSION

ETT are compromised and require conservative repair; conventional crowns could increase frac- ture risk[2,23]. However, Endocrowns, a monolithic bonded restoration, are a CAD/CAM alternative to the conventional crown[24]. No need for posts or ferrule preparation, endocrowns help maintain as well sound tooth structure and are especially indicated in molars presenting with complex root anatomy[25], they provide combined retention and strength, curing with crown and core in a single adhesive unit[26]. The aim of this study was to evaluate the effect of preparation design (conventional versus modified) and base material (EverX Posterior, SDR, ceramic extension) on the fracture resistance and failure modes of lithium disilicate endocrowns.

We found that conventional preparation form provided greater resistance to fracture than the mod- ified (anatomical) design, especially for composite base material. Statistical analysis resulted in statistically significant differences for the EverX posterior groups (p = 0.028); SDR and ceramic groups did not demonstrate significant differences. These outcomes indicate that the performance may not linearly increase with cavity optimization and could even weaken the stress delivery. This is in accordance with the study of Alzahrani et al. which identified no significant effect of design modifications on the stress distribution[27]**.** The conventional flat-but joint pattern in constructs may be more mechanically consistent, whereas morphologic changes may focus loads in least prefera- ble regions[28]. Alternatively, some particular modifications have demonstrated beneficial effects in the literature. El Ghoul et al. obtained higher failure loads by creating inner grooves to enhance the adhesive bonding surface of the endocrowns' walls[22]. Similarly, Abo El-Fadl and Elsewify found that adding a 1–2 mm axial shoulder (a ferrule-like feature) to the preparation resulted in a significant increase in molar endocrown strength[6]. These contradicting results suggest that not all design alterations are positive and their effect might be based on the modification they produce in stress redistribution. Of course, even in the case that some design modifications increase ultimate fracture loads, in some cases this leads to less favorable failure modes. Haralur et al. d had further evidence that the presence of an intraradicular extension (2 mm analogous to a short post) in en- docrowns increased fracture strength, which in turn led to a greater occurrence of deep, irreparable root fractures[28]. This was also true in our study, where the conventional design gave either similar or greater fracture resistance and more favorable failure modes, whereas the modified design, par- ticularly in combination with a ceramic base, led to more catastrophic fractures.

The selection of the base material is of equal importance. Endocrowns with fiber-reinforced com- posite (EverX Posterior) exhibited the highest fracture resistance, followed by bulk-fill composite (SDR), and those with ceramic base extensions presented the lowest resistance. The better perfor- mance of EverX could be due to the E-glass fibers which reinforce the restoration and prevent crack propagation, similar to that reported by Selvaraj et al. and who found a marked increase in strength with the addition of fiber[29]. On the other hand, it has been suggested that the high rigidity of an entire ceramic base is a stress concentrator, which may be accompanied by sudden non- repairable failure[30], this should explain why the ceramic groups had the worst results since it was based on the ceramic cores. These different materials also showed different failure modes: the

EverX endocrowns (but especially the conventional design endocrowns) failed mainly in favorable restorable fractures whereas the ceramic endocrowns failed through catastrophic root fractures[29].

Through failure mode analysis it was found that both preparation design and the material used determined whether or not the fractures were restorable 10 or catastrophic. More favorable (no cata- strophic) Type

I failures were found for conventional preparations, particularly in EverX and SDR; modified preparations showed a trend toward Type V catastrophic root fractures. Conventional EverX posterior had resulted in 70% favorable fractures, whereas with modified EverX 90% was catastrophic failures. This result is similar with Haralur et al., who noticed a greater proportion of unrestorable fractures when internal extensions were incorporated in endocrowns[28]. Moreover, Ib- rahim et al. and Mously et al. restorations with composite base had a higher rate of repairable failures compared to treatments placing sole emphasize on lithium disilicate[30,31].

Limitations and Future Research

A limitation, which was observed for all teeth, was the high fluctuation of the values of the classical fracture resistance, which may have been affected by the examined variation in age and time from extraction. Also, there was no synthetic periodontal ligament and testing was limited to axial static loading that does not completely resemble the dynamic, multi-directional load that occurs in- traorally[32]. Cyclic loading, changing force direction, and advanced imaging (such as sample Scan- ning Electron Microscopy) could be considered in future research to further investigate internal crack growth and failure modes in a more accurately fashion. In addition, long-term clinical trials will be required to confirm in vitro findings.

CONCLUSION

Conventional endocrown preparation designs achieved higher resistance to fracture and more fa- vorable restorable failure modes than did modified anatomical designs. Within the tested base ma- terials, the EverX Posterior offered the best mechanical properties and repairability, then SDR and the worst performance was observed with ceramic base extensions. The results from this study underscore that preparation geometry and original material choice are both important in order to achieve the maximum clinical success and longevity for endocrown restorations.

DECLARATIONS

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Conflict of Interest

The authors declare no conflict of interest.

Ethical Approval

This study was conducted in accordance with the principles of the Declaration of Helsinki and was approved by the Institutional Medical Ethics Committee.

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