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Original article

Effect of Material on The Fracture Resistance of Three-Unit Endocrown Retained Bridge on Endodontically Treated Abutments

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Abstract
This study aimed to evaluate the effect of material selection on the fracture resistance of a three-unit endocrown-retained bridge placed on endodontically treated abutments. Two restorative materials were investigated: lithium disilicate (IPS e.max Press, Ivoclar Vivadent) and high-performance polymer (BioHPP, Bredent GmbH). A total of 14 samples were fabricated using standardized preparation techniques, with each material group comprising seven samples. Endocrown retainers were designed using CAD/CAM technology and cemented with adhesive resin cement (3M RelyX™ Ultimate). The samples underwent thermomechanical aging using a chewing simulator, followed by static fracture testing in a universal testing machine to assess their load-bearing capacity. Statistical analysis revealed that the IPS e.max Press group exhibited higher fracture resistance (1505.8 ± 57.79 N) than the BioHPP group (1352.2 ± 113.54 N), with a statistically significant difference (p = 0.0026). Despite this, both materials demonstrated fracture resistance values exceeding the functional occlusal forces encountered in clinical settings. Endocrown-retained bridges fabricated from IPS e.max Press and BioHPP exhibit clinically acceptable fracture resistance. However, IPS e.max Press demonstrated superior mechanical properties, making it a more reliable choice for endocrown-retained restorations. BioHPP restorations, while slightly less resistant, offer advantages in terms of biocompatibility and wear resistance. Further research is recommended to explore long-term clinical performance.
Keywords:. *Endocrown, fracture resistance, IPS e.max Press, BioHPP, CAD/CAM, adhesive cementation*

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Introduction

The conventional approach for restoring endodontically treated teeth with significant coronal loss traditionally involves using a metal post and core, followed by a complete crown. The introduction of glass fiber posts combined with dentin bonding techniques has simplified the restoration process, making it more biocompatible and cost-effective [1]. Initially, posts were believed to reinforce the remaining tooth structure [2]; however, multiple studies have reported varying outcomes, with a high incidence of root fractures, suggesting that excessive removal of tooth structure for post-placement can further weaken the root [3].
With advancements in high-strength ceramic materials and adhesive dentistry, it is now possible to restore posterior teeth without relying on a post and core [4]. The endocrine serves as a viable alternative for teeth with significant coronal loss. The first report on endocrowns was by Pissis [5]. in 1995, who referred to it as the "monoblock porcelain technique." In 1999, Bindl and Mörmann [6] coined the term "endocrine" to describe a ceramic restoration that extends into the pulp chamber or root canal orifices of an endodontically treated tooth to achieve retention.
Endocrowns are particularly beneficial for teeth with short clinical crowns and calcified, short, or curved root canals, where post and core restorations are not feasible. They are also suitable for patients with limited interocclusal space, which restricts the required thickness for ceramic veneers and metal or ceramic frameworks [7]. However, end crowns are contraindicated when the pulp chamber depth is less than 3mm, the cervical margin width is less than 2mm, or adhesive bonding cannot be ensured [8].
A high-performance polyetheretherketone (PEEK) has recently gained popularity in dentistry. It has been utilized for fabricating implant fixtures, fixed and removable dental prosthesis frameworks, and restorative implant components [9]. A modified version of PEEK, which incorporates 20% ceramic fillers (BioHPP; Bredent GmbH), is employed in prosthesis fabrication through either injection molding or CAD-CAM techniques. The benefits of this material include reduced allergic reactions, excellent mechanical properties, high wear resistance, good polishing ability, and low plaque accumulation [10]. Additionally, using epoxy

resin abutments has facilitated standardization in research, although natural teeth may introduce more significant variability in fracture load results due to their inherent structural differences. Therefore, the concept of using new materials to construct an endocrine-retained bridge is considered in the present study.

Methods

The following materials were used in the current study: I) IPS e.max press (Ivoclar Vivadent), II) Bio HPP (Bredent GmbH). Two intact human teeth (1 maxillary first premolar and one maxillary first molar) were selected for the study to produce (14 samples) prepared to receive an endocrine retainer design. Then, the groups were divided according to the materials into two subgroups (7 samples) according to different materials: 1-endocrine retainer design made by Bio HPP, 2-endocrine retainer design made by IPS e, max. The crowns of the teeth that receive endocrine restorations were cut horizontally using a disk mounted on a CNC machine. The cutting was according to the amount of remaining tooth structure. Both teeth were measured at the highest point of the curvature of the cervical line (2 mm remaining tooth structure above that point). The endocrown internal preparation was made by a CNC machine to be ready for the optical impression (Fig.1 a&b).
For standardization of the designs, the same natural teeth were used; the prepared premolar and molar endocrine designs were mounted in the acrylic cast using a paralleling device. Optical impression was taken using 3Shape D500*, with the 3Shape dental designer software, and the virtual models were designed (Fig.2). The model was produced by forwarding the design STL file to a 3D printing machine. In the 3D printing machine, a solid printed model was built using a DLP projector to sequential planes of data into a photo-activated liquid resin, causing the affected resin to cure from liquid to solid. Then, Epoxy resin duplicated the 3D master models (Fig 3). The construction files for restoration design to be constructed from a lithium disilicate press were first milled into wax using a milling machine. The abutment design preparation was forwarded to the manufacturer software (Exocad) of the milling machine. After the milling process was completed, the milled patterns were separated from the blank; all the patterns were spread, and invests were carried out with IPS press VEST speed. After the investment was set completely, the investment ring was prepared for preheating. Then, the investment ring was removed from the preheating furnace immediately after the completion of the preheating cycle. A cold e-max ingot was placed into the hot investment ring for pressing. After the divesting, all the pressed restorations were immersed in the Invex Liquid for 10 minutes, followed by washing with running water and drying with air, then finished and glazed. The CAD wax models for Bio HPP restoration were milled using a milling machine for standardization, and the wax blank was milled using the same steps as the e.max press restorations. After the pressing procedure, the mold was left for 35 minutes to cool, and then the mold was divested. Then, the frameworks were blasted with 110 µm, 2 bar pressure, and the blasting distance was 3 cm. Followed by the application of a thin coat of vision. Link adhesive is applied to the bio HPP framework before applying the realign composite and cured for 90 seconds using a breLux power unit. For dimensional standardization between E.max and Bio HPP bridges, a silicon index of the wax pattern was taken and used for composite applications. The epoxy models were sandblasted with 50µm, 2 bar pressure. The vita ceramic etching acid gel hydrofluoric acid 9 % concentration is used for surface treatment of e.max restorations according to the manufacturer's instructions. The Bio HPP restorations adhesive surfaces were blasted with aluminum oxide (110 µm) at 2 to 3 bar blasting pressure. Then, all samples were cemented with Adhesive Resin 3M RelyX™ Ultimate cement.

A) Fatigue Test

The thermo-mechanical aging test was conducted using four four-station multi-modal ROBOTA chewing simulators integrated with thermo-cyclic protocol operated on a servo-motor. The specimens were embedded in acrylic resin in the lower sample holder. A weight of 5 Kg, comparable to 49 N of chewing force, was exerted. The test was repeated 75.000 times to simulate the 6-month chewing condition clinically, accompanying thermo-cycling demonstrating the testing parameters used during the test).

B) Static load to fracture after fatigue

All samples were individually mounted on a computer-controlled materials testing machine with a load cell of 5 KN, and data were recorded using computer software. The fracture test was done by compressive mode of load applied occlusal at the pontic using a metallic rod with a round trip (3.4 mm diameter) attached to the upper movable compartment of the testing machine traveling at a cross-head speed of 1mm/min. with a tin foil sheet in-between to achieve homogenous stress distribution and minimization of the transmission of local force peaks. The force was applied until fracture. The first discontinuity from an early crack or catastrophic crown failure was detected. The load at failure manifested by an audible crack and confirmed by a sharp drop at the load-deflection curve recorded using computer software. The load required to fracture

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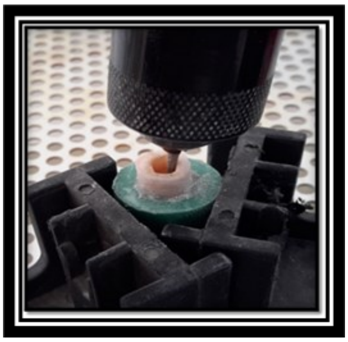
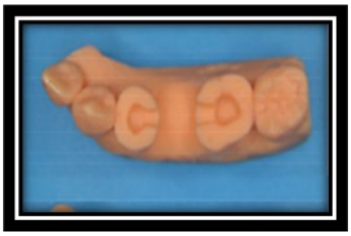
was recorded in Newton.



(Fig 1- a) preparation

(Fig 1-b) optical impression



(Fig 2) virtual model

(Fig 3) epoxy resin model

Results

Data analysis was performed in several steps. Initially, descriptive statistics will be used for each group's results. A two-way analysis of variance ANOVA test of significance was done to compare variables.

Influence of material

It was found that the e.max group recorded statistically non-significant (p>0.05) higher fracture resistance mean values than the Bio HPP group, as indicated by two-way ANOVA followed by pair-wise Tukey's posthoc tests.

Table 1. Comparison between total fracture resistances as a function of material group.

Variable		Mean±SD	Rank	Statistics
Material Group	e.max	1505.8±57.79	A	p-value
	Bio HPP	1352.217±113.54	B	0.0026*

*Ns; non-significant (P>0.05). *; significant (P<0.05)*

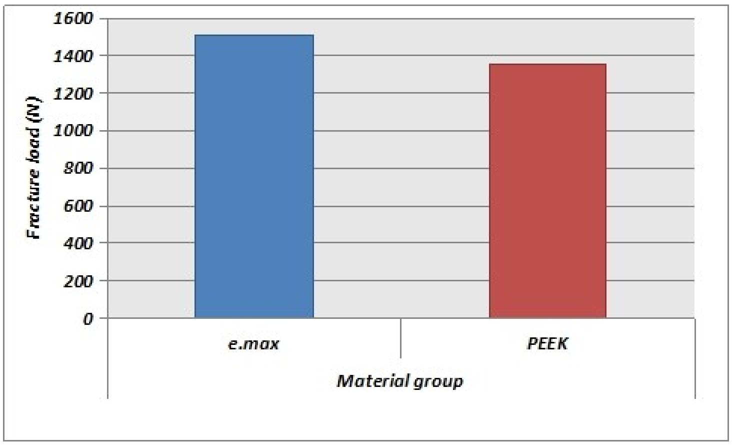


Figure 4. Column chart of fracture resistance mean values as a function of the material group.

Discussion

Endocrowns are monolithic overlays that share similarities with inlays and onlays regarding preparation and cementation. They offer several advantages over conventional crowns, such as minimizing the number of interfaces within the restorative system, thereby reducing stress concentration due to decreased non-homogeneous materials. Additionally, their preparation is more conservative than that of traditional crowns, with minimal involvement of the biological width. Compared to post-and-core restorations, the bonding surface provided by the pulpal chamber in end crowns is often comparable or even superior to that achieved with an 8 mm deep radicular post. However, end crowns also present some drawbacks, including the risk of debonding and root fractures, which result from differences in the modulus of elasticity between the more complex ceramic material and the softer dentin [11].

The current study evaluated different restorative materials to determine whether an endocrine-retained bridge could be a viable option for replacing a missing tooth adjacent to an endodontically treated tooth. The materials used were E.max Press, and Bio HPP veneered with composite, which were employed to construct three-unit bridges featuring endocrine retainers. The objective was to assess fracture resistance according to the material used. Hudis and Goldstein [12] asserted that inlay/onlay restorations offer the necessary protection and promote clinical success by preserving as much tooth structure as possible. With advancements in adhesive techniques and ceramic materials, restorations relying on adhesion have demonstrated superior performance, as macro-retentive designs are no longer essential when sufficient tooth surface is available for bonding. This led to the development of endocrine restorations. While natural teeth provide the most clinically relevant testing scenario, size, shape, and quality variations make standardization difficult. Therefore, alternative abutment materials, such as epoxy resin, are often used for consistency in testing [13].

The choice of abutment material is crucial since it significantly influences the fracture strength of restorations under load [14]. Scherrer and de Rijk [15] demonstrated that the fracture resistance of all-ceramic crowns is affected by the elastic modulus of the abutment material, with higher elastic modulus values correlating with increased fracture strength. Omori et al. [16,17] indicated that the type of cement used also impacts the fracture strength of all-ceramic crowns. Bindl et al. [6] reported that when adhesive resin cements are utilized, loads are transmitted more directly to the underlying structure than conventional cements in all-ceramic restorations. Using ceramics with adhesive cementation techniques allows for the conservation of tooth structure and enhances the esthetics of posterior teeth. Adhesive luting methods reinforce the tooth, reduce the adverse effects of cusp flexure, and enhance crown stiffness by improving adhesive bonding, cohesive strength, and stress distribution [18]. Resin cement used in adhesive restorations is flexible and deforms under stress, leading to higher fracture resistance. The success of ceramic inlays depends on creating a strong adhesive interface between the tooth and the ceramic material. Additionally, the elastic modulus of the luting agent plays a role in determining fracture strength. Cubas et al. [19] observed that luting agents with a higher elastic modulus increased the fracture strength of partial ceramic restorations.

All specimens in this study were subjected to vertical loading in a universal testing machine until failure, ensuring uniform standardized loading parameters. Mechanical fracture tests were conducted to quantify the influence of different restorative materials on fracture resistance under increasing load. Although these tests generate failure loads exceeding the forces exerted by regular stomatognathic system movements, they simulate extreme conditions, such as when an individual bites down on a solid object, concentrating force on a single tooth. If the tooth is structurally weakened or improperly prepared, this can result in a fracture of the tooth, the restoration, or both [20]. The occlusal force during clenching has been reported to range between 520 and 800 N, with a minimum fracture resistance of 1,000 N required for the long-term success of all ceramic fixed partial dentures (FPDs) [21]. This study demonstrated that the fracture resistance for both materials exceeded this range.

Regarding material type and its impact on fracture resistance, E.max groups recorded slightly higher mean fracture resistance values than Bio HPP groups, although the difference was statistically insignificant ($p<0.05$). Dalpino et al. [22] analyzed the fracture resistance of teeth restored with direct and indirect composite resin and ceramic restorations. They found that bonded indirect ceramic restorations withstood higher loads than direct and indirect composite resin restorations. Ceramic-based bonded restorations are the preferred choice for teeth compromised by extensive cavity preparations. Lakshmi et al. [23] examined the impact of connector dimensions on the stress distribution of lithium disilicate inlay-retained fixed dental prostheses. They concluded that lithium disilicate is suitable for all-ceramic inlay-retained FPDs with a minimum connector dimension of 4x4 mm.

For Bio HPP FPDs, no framework fractures were observed; however, the weakest area was the pontic, where the veneering composite exhibited low resistance to occlusal forces, leading to delamination. Delamination,

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or adhesive failure, can be influenced by various factors, including veneer thickness, mechanical properties, magnitude and direction of applied forces, residual stresses, internal defects, and veneer strength [24]. Layered composite restorations tend to have lower flexural strength and fracture toughness than the core material (Bio HPP) since the veneering layer comprises less than half of the total restoration thickness. Consequently, this veneering composite represents the weakest link, prone to chipping or fracturing under functional loads.

Monolithic glass-ceramic restorations offer significant advantages, such as enhanced structural integrity and strength, by eliminating the need for a veneering layer and its associated bond interface [25]. Schmidlin et al. [26] noted that achieving a strong bond between PEEK frameworks and veneering resin composites remains a challenge due to PEEK's low surface energy and resistance to mechanical and chemical surface modifications. This finding aligns with Mutlu et al. [27] who reported that the primary failure mode of bi-layered restorations was veneering chipping. Similarly, Simon et al. [28] concluded that non-veneered PEEK FPDs demonstrated higher fracture loads than their veneered counterparts. Gohring and Ross [29] evaluated the fracture strength of inlay-retained FPDs reinforced with glass fibers. They found that the primary failure mode was delamination of the veneering material from the framework. This was attributed to the low elastic modulus, insufficient flexural strength, and the composite's inability to prevent crack propagation.

Although PEEK frameworks without veneering exhibit higher fracture loads, veneering remains necessary for clinical use due to aesthetic considerations. A prior study reported that three-unit PEEK frameworks without veneering had a mean fracture load of 1,383 N [30]. Another study investigating the impact of fabrication methods on monolithic PEEK FPDs found fracture loads ranging between 1,738 and 2,354 N [9]. Despite the findings of this study, certain limitations should be acknowledged. The load application was unidirectional and limited to a single standardized area, which differs from the complex functional forces encountered in clinical settings. Future studies should incorporate testing conditions that better simulate masticatory forces. Additionally, using epoxy resin abutments facilitated standardization, though natural teeth might introduce more variability in fracture load results due to their inherent differences in structure.

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المستخلص

تهدف هذه الدراسة إلى تقييم تأثير اختيار المواد على مقاومة الكسر لجسر مكون من ثلاث وحدات محتفظ به في التاج الداخلي الموضوع على الدعامات المعالجة اللبية. تم التحقيق في مادتين تصالحيتين: ثنائي سيليكات الليثيوم (IPS e.max Press، Ivoclar Vivadent) والبوليمر عالي الأداء (BioHPP، Bredent GmbH). تم تصنيع ما مجموعه 14 عينة باستخدام تقنيات التحضير الموحدة، حيث تضم كل مجموعة مواد سبع عينات. تم تصميم مثبتات Endocrown باستخدام تقنية CAD/CAM وتدعيمها بلاصق (RelyX™ Ultimate3 M). و خضعت هذه العينات للضغط باستخدام جهاز محاكاة المضغ، متبوعا باختبار الكسر الثابت لتقييم قدرتها على تحمل الكسر. كشف التحليل الإحصائي أن مجموعة IPS e.max Press أظهرت مقاومة أعلى للكسر (1505.8 ± 57.79 N) من مجموعة BioHPP (1352.2 ± 113.54 N)، مع اختلاف إحصائيا (p = 0.0026). على الرغم من ذلك، أظهرت كلتا المادتين قيم مقاومة الكسر التي تتجاوز قوى الإطباق الوظيفية التي تمت مواجهتها في البيئات السريرية. تظهر الجسور المحتفظ بها داخل التاج والمصنعة من IPS e.max Press وBioHPP مقاومة كسر مقبولة سريريا. ومع ذلك، أظهرت IPS e.max Press خصائص ميكانيكية فائقة، مما يجعلها خيارا أكثر موثوقية للترميمات التي يحتفظ بها التاج الداخلي. على الرغم من أن ترميمات BioHPP أقل مقاومة قليلا، حيث توفر مزايا من حيث التوافق الحيوي ومقاومة التآكل.