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EVALUATION OF FRACTURE RESISTANCE OF ONLAY FABRICATED BY 3D PRINTED COMPOSITE AND HYBRID CERAMIC MATERIALS

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ABSTRACT

Purpose: The aim of this study was to assess and compare the fracture resistance of. onlays fabricated using 3D printed composite material (Next Dent C&B) and hybrid ceramic (Vita Enamic) material for upper premolar dental restorations.

Materials and Methods: Forty onlay specimens were fabricated, with 20 onlays made from 3D printed composite resin and 20 from hybrid ceramic (Vita Enamic) material. All specimens were prepared with standardized dimensions and subjected to fracture resistance test using a universal testing machine. Applied load at fracture point was recorded for each specimen to assess material performance.

Results: The results showed that hybrid ceramic (Vita Enamic) onlays exhibited a greater average fracture resistance than 3D printed composite (Next Dent C&B)onlays. However, statistical analysis revealed that the difference in fracture resistance between the two materials was not significant ($p > 0.05$).

Conclusion: Both 3D printed composite and hybrid ceramic (Vita Enamic) materials demonstrated comparable fracture resistance in the context of upper premolar onlay restorations. Vita Enamic demonstrated a higher average fracture resistance, but no significant statistical difference was observed between the materials

KEYWORDS: Fracture resistance, hybrid ceramic, 3d printed composite

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INTRODUCTION

The demand for durable dental restorations has led to the development of various materials for posterior onlays, with a focus on optimizing mechanical properties such as fracture resistance. Onlays, which are indirect restorations used for the restoration of damaged posterior teeth, must withstand significant functional stresses **(Bonfante, E.A., et al 2023).** Traditionally, materials like ceramics and composite resins have been employed for onlay fabrication, each exhibiting varying degrees of mechanical performance and wear resistance **(Dionysopoulos, D., et al 2021).**

With the recent advancements in 3D printing technologies, 3D printed composite resins have become promising alternatives because of their ability to combine the advantages of both composite resins and the customization offered by digital fabrication **(Ma, T., et al 2024).**

Indirect restorations like inlays and onlays can be made in the lab or at the chairside using CAD/CAM technology or a 3D printer. Glass ceramics and resin composites are commonly used for CAD/CAM restorations. However, glass-matrix ceramics have some drawbacks, including brittleness and wear on opposing teeth, despite their improved strength and appearance **(Souza, J. C., et al 2020).** The polymer network helps absorb chewing forces better than glass ceramics. Compared to 3D printed composite materials, these hybrid materials offer better edge stability, allowing for thinner restorations, easier machining, and less brittleness. **(Zimmermanna M, et al 2013).**

Fracture resistance refers to the maximum strength and pressure a restorative material and tooth can handle before damage occurs. It helps clinicians assess different materials and choose the best one for restoration and preparation **(Ferooz M, et al 2015).**

MATERIALS AND METHODS

I-Materials:

The following materials were used in this study:

- **3D Printed Composite Resin:** The 3D printed composite resin used in this study was Next Dent C&B
- **Hybrid Ceramic:** The hybrid ceramic material used in this study was Vita Enamic

II. Specimens Grouping:

Fourty only were constructed and divided into two groups based on restorative materials :

Group I: (n=20) MOD onlay restoration hybrid ceramic (Vita Enamic).

Group II: (n=20) MOD onlay restoration 3D Printed composite (Next Dent C&B).

Specimens were mounted and were exposed to fatigue testing by cyclic loading then subjected to compression load until failure by universal testing machine (Model 3345; Instron Industrial Products, Norwood, MA, USA.) .

III. Steps of Only Specimens' Preparation:

A- Collection of The Teeth:

Freshly extracted maxillary first premolars were gathered from surgical and orthodontic department, Faculty of Dentistry hospital, Beni Suef University. The teeth were examined to ensure they were intact, non-restored, and free from caries, cracks, and significant occlusal erosive lesions. The tooth was cleaned by ultrasonic device from any surface debris then it was ready for sample construction. The tooth was cleaned and disinfected by immersion in 5% sodium hypochlorite solution (JK dental vision, 5% sodium hypochlorite solution with surface modifiers) **(Kalantari MH, et al 2014)** and stored in distilled water (Purified water, pharmapack pharmaceutical industries) till use.

B- Mold Preparation:

To mimic the periodontal ligament, the roots of all teeth were immersed in melted wax (Cavex Holland BV, The Netherlands) to form a layer of 0.2 to 0.3 mm. The teeth were then placed in a cylindrical PVC ring (1.4 x 2 cm) filled with auto-polymerizing acrylic resin (Acrostone, Cairo, Egypt) up to 2 mm below the cement-enamel junction (C.E.J). The wax spacer was removed from the root surface using hot water and a wax knife.

C-Standardized Tooth Preparation:

Before preparation, a condensation silicone rubber index (Speedex, Coltene Whaledent, Switzerland) was made for each tooth to standardize the preparation thickness.

Cavity preparation was performed using a high-speed handpiece (Allegra TE-95, W&H GmbH, Bürmoos, Austria) with water cooling, employing fissure diamond instruments from the onlay preparation set 4261 (Komet, Lemgo, Germany) to create a cavity with a 6-degree taper **(Abdel Ghany, S. G., et al., 2022)**.

The dimensions of the cavity preparation were as follows: The occlusal box was 3 mm deep and 2.5 mm in bucco-lingual width, with rounded internal angles, diverging buccal and lingual walls (6°), and cavo-surface angles approximately 90 degrees. The proximal box was 2.5 mm wide, 1.5 mm deep, and 2 mm in height **(Abdel Ghany, S. G., et al., 2022)**. To prepare the onlays, the palatal cusps of the prepared MOD cavities were reduced by 2 mm, following the anatomical contour of the occlusal surface. A 1.5 mm rounded shoulder finish line was placed 2 mm cervical to the palatal occlusal reduction using a long round-ended taper diamond #850-023 (FG x5, Komet, Germany)**. Figure (1)**

Fig. (1) Only cavity preparation

D. Epoxy Resin Dies Construction:

A custom-made cylindrical metallic perforated tray with an internal diameter of 20 mm and a height of 45 mm was constructed. Forty impressions of the prepared teeth were taken using condensation silicone rubber base (Speedex, Coltene Whaledent, Switzerland), by hand-mixing the heavy paste and catalyst according to the manufacturer's instructions.

The impression was placed into the perforated tray, and the prepared tooth was embedded in the impression. After the impression set, the tooth was removed. Epoxy dies were then fabricated using chemically activated epoxy resin (Kemapoxy 150, CMB, Egypt). The two components (A & B) of the Kemapoxy resin were thoroughly mixed in a vibrator (Vibromaster Bego Bremer, GmBA, Germany) for two minutes. Component B was added to component A in a 2:1 weight ratio, and the mixture was left for ten minutes before pouring to ensure a homogeneous consistency. The mixture was poured into the impressions and left for 48 hours to complete setting, achieving dimensional stability. After the epoxy dies were removed from the impressions, they were finished using a low-speed straight handpiece (Sirona Dental Systems GmbH, Fabrikstra, Beneshiem, Germany) with a cylindrical finishing stone (Komet Dental, Gabr Lemgo, Germany) and polished with pumice (Dental Lab Pumice, Dentsply, USA) using a smooth electronic brush. The epoxy dies were then ready for crown construction **(Øilo M, et al., 2013).**

IV- Fabrication of Only restoration:

a. Digital Optical Impression:

The epoxy die of prepared tooth was scanned using inEosX5(*Dentsply Sirona, Milford, USA*)**.** The prepared tooth was coated with Occlutec optical spray (*Renfert, Giesswiesen, Hilzingen, Germany*) To improve the quality of the digital impression**.** The scan's precision ensures that a complete digital model of the tooth is created without any defects. **Figure (2)**

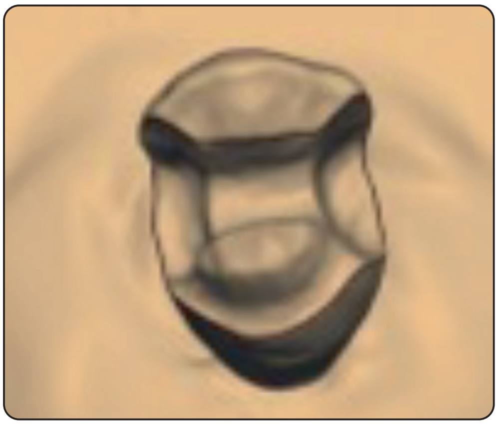

Fig. (2) Scan only preparation

b. Computer Aided Restoration Designing.

All restorations were designed using Exocad software (Exocad 2023, Exocad Dental, Darmstadt, Germany). The margins of the restorations were identified and outlined, followed by determining the optimal path of insertion for the restoration. **Figure (3)**

C. Fabrication of final restoration

- 3D Printed Composite Group: Onlays were fabricated using the NextDent C&B 3D printing system (NextDent, Netherlands). The design of the onlay was made using CAD software (Exocad, Germany), followed by 3D printing the specimens using a DLP printer.
- Hybrid Ceramic Group: The Vita Enamic hybrid ceramic onlays were fabricated using the CAD/

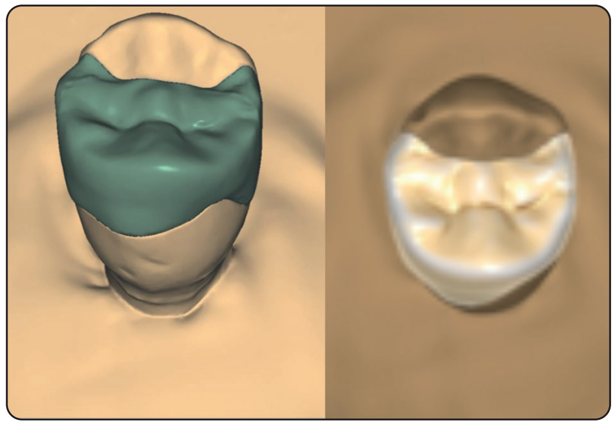

Fig. (3) Design of only restoration

CAM system (Exocad, Germany). The onlays were milled from pre-sintered blocks following the manufacturer's instructions. After milling, the specimens were sintered at the recommended temperature (850°C) to attain the final material properties. The dimensions of these onlays were kept identical to the composite group to ensure consistency in testing.

V. Try-in of Samples

Each only restoration was placed into the corresponding prepared epoxy die to check seating, marginal fit and accuracy under proper visualization and magnification by magnifying loupes(*Economy Speed PAK, China*).

VI. Cementation of Only restoration

For Vita Enamic only

Following the manufacturer's recommendations, surface treatment was performed on the fitting surface of each Vita Enamic restoration using 9% hydrofluoric acid gel (Ultradent Products, Australia) for 90 seconds. The surface was then rinsed with an air-water spray for 30 seconds, followed by washing with distilled water and air drying.

Each onlay was coated with a silane coupling agent containing adhesive phosphate monomer (Pentron Clinical, 1717 West Collins, Orange, CA

92867, USA) and left to sit for 30 seconds, then dried using an air syringe, following the manufacturer's instructions.

All onlay cavities were thoroughly cleaned using pumice and water, then rinsed and dried. The cavities were etched with 37% Eco Etch (Ivoclar Vivadent AG, Schaan, Liechtenstein) applied to both the enamel and dentin of the tooth preparation. Typically, the enamel was etched for 30 seconds, and the dentin for 15 seconds.

Rinse the acid thoroughly with water and lightly dry the tooth, ensuring the dentin remains slightly moist.

Self-adhesive dual cure Bisco, duo-link universal™ (BISCO, Duo-Link Universal™ . USA) was distributed on the inner surface of the ceramic onlay, and the onlay were carefully placed on the epoxy dies, ceramic only were initially seated on the epoxy die with finger pressure first then a static load of 6N load **(Zortuk M, et al 2010)** was applied for 5minutes by loading device and the excess was removed using explorer (Dentsply, USA.). Each onlay was light-cured from all angles for 60 seconds using a Bluephase curing light (Ivoclar Vivadent, Schaan, Liechtenstein)

Once all the onlays were fully cemented, the specimens were prepared and ready for testing

For 3D Printed composite only

Apply 37% Eco Etch (Ivoclar Vivadent AG, Schaan, Liechtenstein) to both the enamel and dentin of the tooth preparation. Typically, etch the enamel for 30 seconds and the dentin for 15 seconds

Rinse the acid thoroughly with water and gently dry the tooth, ensuring the dentin remains slightly moist.

Self-adhesive dual cure Bisco, duo-link universal™ (BISCO, Duo-Link Universal™. USA) was distributed on the inner surface of the 3D printed composite only, and the only were then seated on the epoxy dies, and initially seated on the epoxy die with finger pressure first then a static load of 6N load **(Zortuk M, et al 2010)** was applied for 5minutes by loading device and the excess was removed using explorer (Dentsply, USA.).

Each onlay was light-cured from all angles for 60 seconds using the Bluephase light (Ivoclar Vivadent, Schaan, Liechtenstein)

VII. Thermocycling:

Before testing, all crown specimens were stored in distilled water at 37°C for 2 days. Additionally, they underwent thermo cycling between water temperatures of 6.6°C and 55.5°C. Most studies cited only hot and cold temperature points, with the number of cycles varying from 1 to 1,000,000, with an average of about 10,000 cycles and a median of 500 cycles.

The dwell times were often not specified, but the mean dwell time was 53 seconds, with a median of 30 seconds and a range from 4 seconds to 20 minutes. In some cases, a longer dwell time of 23 seconds was used with an intermediate temperature of 37°C, while a shorter dwell time of 4 seconds was applied at temperature extremes, using an automated thermal cycling machine (Robota Automated Thermal Cycle; BILGE, Turkey). These conditions likely aim to replicate the expected intraoral timing, as it is challenging to mimic oral conditions in in-vitro studies.

The oral environment exposes teeth to various challenges, such as pH and temperature changes from food consumption, as well as mechanical loading during mastication. A total of 1,000 cycles is considered to represent two years of clinical survival, as described in ISO/TS 11405 **(Gale MS, et al 1999) (Morresi AL, et al 2014)**

VIII. Fracture Resistance Test:

Each onlay restoration, cemented to its corresponding epoxy die, was individually mounted in the lower fixed grip of a computer-connected universal testing machine (Model 3345; Instron Industrial Products, Norwood, MA, USA) by tightening screws. The assembly was subjected to static compressive loading using a 5 kN load cell, and data were recorded with computer software (Bluehill Lite Software, Instron® Instruments) until fracture occurred.

A steel rod with a round tip (3.6 mm diameter) attached to the upper movable compartment of the testing machine, traveling at a cross-head speed of 1 mm/min, was used. A tin foil sheet (Nour Foil, Queen, Egypt) was placed between the rod and the occlusal surface to achieve uniform stress distribution and minimize local force peaks. The fracture of the crowns was indicated by the audible sound of a crack and a sharp drop in the load-deflection curve. The load required for fracture was determined by the audible crack and the sharp drop recorded in the load-deflection curve using the software. The load to fracture was measured in Newtons.

All data were collected, tabulated, and subjected to statistical analysis.

RESULTS

A total of 40 onlay specimens were fabricated and tested for fracture resistance, with 20 onlays made from 3D printed composite resin and 20 onlays made from hybrid ceramic material. The fracture resistance values for each group were recorded in Newtons (N) and are presented in Table 1.

Upon examining the mode of fracture, it was observed that both materials exhibited predominantly catastrophic fractures at the occlusal surface under high load conditions. However, a few specimens in the hybrid ceramic group exhibited minor chipping along the edges without complete fracture, indicating the material's potential for slight deformability under stress.

TABLE (1) Mean Fracture Resistance of Onlays Fabricated by 3D Printed Composite and Hybrid Ceramic Materials

Material	Mean Fracture Resistance (N)	Standard Deviation (N)
3D Printed Composite	753.2	45.1
Hybrid Ceramic	801.4	39.8

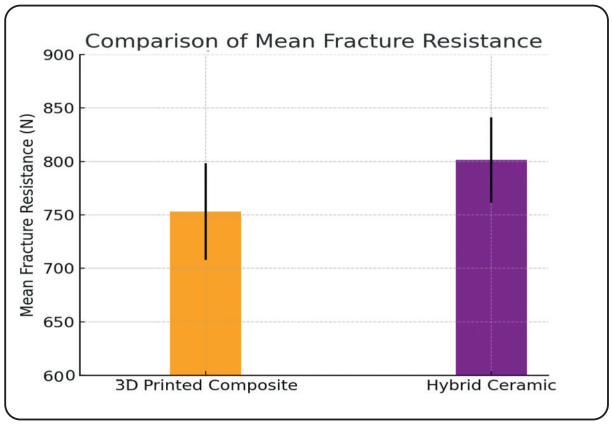

Fig. (4) Bar Chart: Comparison of Mean Fracture Resistance

The results show that while hybrid ceramic onlays exhibited higher fracture resistance on average, the difference between the two materials was not statistically significant, suggesting both materials may be suitable for clinical use in posterior onlay restorations.

Comparison of Mean Fracture Resistance

The following chart compares the mean fracture resistance of 3D Printed Composite and Hybrid Ceramic materials, including standard deviation error bars. **Figure (4)**

Statistical Analysis

The data were analyzed using SPSS software version 24 (IBM Corp, USA). The mean fracture resistance values for each group were calculated and compared using an independent t-test. A p-value of less than 0.05 was considered statistically significant.

Descriptive statistics were also performed to assess the fracture patterns observed in both groups.

The mean fracture resistance for the 3D printed composite group was 753.2 N, with a standard deviation (SD) of 45.1 N. In comparison, the hybrid ceramic group showed a mean fracture resistance of 801.4 N, with a standard deviation (SD) of 39.8 N. Although the hybrid ceramic onlays had a higher mean fracture resistance, this difference was not statistically significant ($p > 0.05$) when compared to the 3D printed composite group.

DISCUSSION

The aim of this study was to assess the fracture resistance of onlays fabricated from 3D printed composite resin and hybrid ceramic materials, two options that have gained attention in modern restorative dentistry. The results of this study showed that although hybrid ceramic onlays had a higher mean fracture resistance than 3D printed composite onlays, the difference was not statistically significant ($p > 0.05$). This outcome aligns with findings from previous studies investigating the mechanical properties of these materials, indicating that both types of onlays could be considered viable options for posterior restorations in clinical practice. **(Moussa, C.,et al 2024) .**

The mean fracture resistance observed for the hybrid ceramic group was 801.4 N, compared to 753.2 N for the 3D printed composite group. While the hybrid ceramic onlays showed higher fracture resistance, The difference between the two materials was negligible and did not reach statistical significance. This result aligns with a study by **(Di Fiore, A.,et al 2024).**which found that 3D printed composite resins exhibited competitive mechanical properties compared to traditional materials. Other studies have similarly reported that composite resins, despite having slightly lower fracture resistance than ceramics, can still perform adequately in posterior restorations under normal masticatory forces **(Desai, P. D., et al 2011) .**

The 3D printing technology used in this study allows for precise control over the material properties and ensures that the printed composite resin has a uniform structure, contributing to its overall fracture resistance. Previous research has suggested that advances in additive manufacturing have made 3D printed composite materials increasingly comparable to traditional materials in terms of mechanical properties **(Alghauli, M. A., eta al 2024) .**

On the other hand, the hybrid ceramic material used in this study, Vita Enamic, has been reported to have excellent fracture resistance due to its combination of ceramic and polymer phases, which enhance its toughness **(Saleh, A. R. M.,et al 2021)** Hybrid ceramics have been shown to provide superior resistance to fractures in clinical conditions, particularly in the posterior region, where they are subjected to significant masticatory forces **(Alnajjar, F. A.,et al 2024)** While the hybrid ceramic group in this study did exhibit a higher mean fracture resistance, the difference from the composite group was not substantial enough to be statistically significant. This may suggest that, while hybrid ceramics are more resistant to fractures in certain cases, modern 3D printed composite materials are approaching comparable levels of fracture resistance for clinical use.

In terms of fracture modes, both materials predominantly exhibited catastrophic fractures under load. However, some specimens in the hybrid ceramic group displayed minor chipping, which is consistent with findings from other studies that suggest hybrid ceramics, while offering higher fracture resistance, may still be prone to surface damage under extreme forces **(Hany, C.,et al 2017)** This suggests that hybrid ceramics may be more resilient to bulk fracture, but both materials could experience superficial damage in clinical settings, particularly under high occlusal loads.

The clinical implications of these findings are significant. Both 3D printed composite resins and hybrid ceramics are viable options for posterior onlay restorations. Although hybrid ceramics provide slightly higher fracture resistance, 3D printed composites offer advantages such as faster production times, lower cost, and ease of fabrication, which may make them attractive for use in clinically demanding environments where turnaround time is crucial(**Duarte Jr, S.,et al 2024)** As additive manufacturing technologies continue to improve, it is expected that 3D printed composite resins will further close the gap in terms of mechanical properties when compared to traditional materials.

Limitations and Future Research

Despite the useful insights gained from this study, there are several limitations to consider. First, the study was conducted under in vitro conditions, which may not entirely replicate the complexity of the oral environment, including factors such as thermal cycling, moisture, and long-term masticatory forces. Long-term clinical studies would be valuable to better understand the performance of both materials in vivo. Additionally, future studies could investigate the fatigue resistance, wear resistance, and esthetic outcomes of 3D printed composite resins and hybrid ceramics, as these properties are critical for the long-term success of posterior restorations.

CONCLUSION

This study demonstrated that while hybrid ceramic onlays exhibited slightly higher fracture resistance than 3D printed composite onlays, the difference was not statistically significant. Both materials showed comparable performance under simulated loading conditions, suggesting that 3D printed composite resins may be a suitable alternative to hybrid ceramics for posterior onlay restorations, particularly in clinical settings where ease of fabrication and cost are important considerations. Additional research is required to assess the long-term clinical performance of both materials in practical, real-world settings.

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