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EVALUATION OF MARGINAL GAP AND FRACTURE RESISTANCE OF DIFFERENT CAD/CAM BLOCKS FOR INDIRECT RESTORATIONS OF MUTILATED MOLAR TEETH

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ABSTRACT

Aim: To evaluate fracture resistance and vertical marginal gap in permanent molars restored with nano-ceramic hybrid CAD/CAM material (Grandio blocs) and reinforced composite CAD/CAM material (BRILLIANT Crios Block) compared to the IPS e.max ceramic Onlay restoration.

Methods: Total of 36 cracks and caries-free human mandibular first molars, extracted for periodontal reasons, selected and randomly assigned into three groups (n= 12). Group (A1) received onlay restorations: Grandio blocks, Group (A2) onlay restorations: BRILLIANT Crios blocks and Group (A3) onlay restorations: IPS e.max ceramic. Teeth were mounted on Teflon molds; standardized cavities were prepared by CNC milling machine. Restorations were fabricated by Cerec in-Lab CAD/CAM and cemented after surface treatment using Theracem self-adhesive resin cement. Specimens were subjected to thermocycling (5000 cycles). Marginal gap was captured using CCD digital camera mounted on stereo microscope, fracture resistance was recorded using computer-controlled materials testing machine with a load of 5 kN. Results were analyzed statistically using student's "t" test. Level of significance was taken at $P < 0.05$.

Results: Regarding vertical marginal gap, IPS e.max group recorded less marginal gap in all surfaces at different points showing statistically significant difference compared to hybrid composite groups ($P<0.016$). Regarding fracture resistance, IPS e.max group recorded slightly lower mean value when compared with hybrid composite groups, showing no statistically significant difference ($P>0.05$) between groups.

Conclusion: The use of IPS e.max press or hybrid composite blocks in combination with adhesive technologies can lead to more conservative, economic, and esthetic approach in restoration of heavily compromised teeth.

KEYWORDS: Marginal Gap, Fracture Resistance, CAD/CAM Blocks, reinforced Composite blocks, nanoceramic hybrid blocks, Onlay restorations.

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INTRODUCTION

In the early 1980s, the concept of bonded all-ceramic inlays and onlays was introduced to the field of dentistry *(Malament et al, 1999)*. The increasing demand for aesthetics in dentistry led to the development of new all-ceramic systems for fabricating ceramic inlays and onlays *(Felden et al, 1998)*. Indirect restorations, such as onlays, have gained popularity because they not only enhance tooth strength but also require less composite resin as a luting *agent (Sundaram et al, 2020)*. Adhesive total-cuspal-coverage restorations (overlays rather than crowns) are recommended to improve coronal mechanical resistance and reduce fracture risk *(J Fan et al, 2021)*. Recent advancements in resin luting agents and ceramics with improved aesthetics and durability have made ceramic onlays more viable. Ceramic and composite blocks have been introduced for fabricating indirect restorations using CAD/CAM technologies *(Salama, 2019)*.

A variety of restorative techniques with minimal invasion of the dental tissues have been reported. These techniques preserve tooth structure. As a consequence, the development of new restorative materials has been based on the concept of microretention which allows better conservation of the dental structure (*Peutzfeldt A., 1995*). Minimally invasive dentistry has become a field of great interest in modern restorative dentistry. Preserving tooth structure is critical for the longevity of teeth and restorations (*Van Dijken JW V, 2010*). The ceramic inlay preparations with 5.5 to 27.2% tooth structure removal are increasing, along with all-ceramic complete crown preparations, which are more invasive and result in 67.5 to 72.3% tooth structure removal. The onlays and partial coverage ceramic crowns, have been reported to remove half the amount of tooth structure compared to a complete coverage metal ceramic crown *(Edelhoff D, 2002)*. And so, to reduce loss of tooth tissue and to improve esthetic results, inlay and onlay restorations are good treatment choices for large cavities in posterior teeth *(Dioguardi et al, 2021)*.

In-vitro studies are suggested to validate their applicability and performance. These tests can be conducted quickly and offer benefits such as reproducibility and the ability to standardize test parameters *(Kern M et al, 1999)*. The physical properties and performance of new dental materials need to be evaluated before they can be recommended for clinical use *(Ritter JE, 1995)*. Therefore, this study aimed to evaluate the impact of various materials used for onlay fabrication on the vertical marginal gap and fracture resistance of molar teeth. The null hypothesis was that all tested materials would perform simultaneously with no significant difference regarding the marginal gap and fracture resistance.

MATERIALS AND METHODS

Materials

The CAD/CAM blocks materials:

1. **Nano-ceramic hybrid Grandio blocks:** (VOCO GmbH, Germany).
2. **Reinforced composite BRILLIANT Crios blocks:** (Coltene, Germany).
3. **IPS e.max Press:** (Ivoclar Vivadent, USA)

luting cement:

Theracem self-adhesive resin cement: (BISCO, USA).

Materials used in surface treatment of the ceramic:

1. **Buffered Hydrofluoric acid gel (9.5%):** (BISCO, USA)
2. **Pre-Hydrolyzed Silane Primer:** (BISCO, USA)

Materials used in surface treatment of the tooth structure

1. **37% phosphoric acid etchant gel:**_(Ivoclar Vivadent, USA)
2. **All bond Universal Light-Cured Dental Adhesive**: (BISCO, USA)

Sample Size Calculation

In a previous study by *Saridag et al in 2013* the fracture resistance within emax onlay group was normally distributed with a mean and standard deviation of 1673.6±677 MPa. By using very large cohen's d effect size of 1.2 we will need to study 12 samples per group to be able to reject the null hypothesis that the population means of the experimental and control groups are equal with probability (power) 0.8. The Type I error probability associated with this test of this null hypothesis is 0.05. Sample size was calculated using PS Power and Sample for windows version 3.1.6 using independent t test.

Study Design

A total of 36 extracted intact, crack and caries-free human mandibular first molar, which were extracted for periodontal reasons selected for this study (n= 12). Group (A1) received onlay restorations using nano-ceramic hybrid Grandio blocks, Group (A2) received onlay restorations using reinforced composite BRILLIANT Crios blocks, and Group (A3) received onlay restorations using IPS e.max ceramic onlay restoration. The fracture resistance and vertical marginal gap were evaluated where the marginal gap of the restoration was captured by CCD digital camera[*]* mounted on a stereo microscope[**]** and the fracture resistance was assessed by individually mounting the samples on a computer controlled materials testing machine (Model 3345; Instron Industrial Products, Norwood, MA, USA) with a load cell of 5 kN and data were recorded using computer software (Instron® Bluehill Lite Software).

* Olympus Dp 10, Japan

** Olympus SZ – PT, Japan.

Sample selection:

For the purpose of standardization, the teeth were selected with approximate similarity in crown size, length and shape. They were of average dimensions (9 ± 0.5 mm) mesio-distal width, and of bucco-lingual width (10mm ± 0.5mm). All dimensional measurements were taken at the proximal cementoenamel junction (C.E.J) level using a digital caliper. All gingival remnants were removed; the crowns were cleaned and scaled with hand instrument and polished with a rotating brush and pumice. Then the collected teeth were stored in distilled water containing 0.1 % thymol at 4oC till use from the day of extraction to keep them hydrated and prevent cracking during cavity preparation.

Samples preparation:

Fabrication of mold and centralizing devices:

Specially designed cylindrical Teflon mold formers having 2cm length and 2cm internal diameters were constructed. Its cylindrical tube used for holding of the acrylic resin and the tooth inside it. A specially designed centralizing metal device was constructed to allow accurate centralization of the teeth in the acrylic resin.

Teeth Mounting and Periodontal ligament simulation

Regarding periodontium simulation, root surfaces were covered by 0.2 – 0.3mm layer of melted wax 2mm below the cement enamel junction (C.E.J). The wax spacer was removed from the root surface using hot water. The space obtained was filled with Polyether impression material (Elite HD+, Zhermack S.p.A., Rovigo Italy) then teeth were mounted vertically with the long axis parallel to the center of the mold within acrylic resin until the level of 2mm before the cervical line, all specimens were embedded up to 2mm below the CEJ to simulate the natural biologic width. Putty silicone (Hydrorise putty- fast set, Zhermack SpA, Italy) was employed to create indices for the occlusal anatomy of the teeth to maintain standardized preparation of all specimens and to fabricate provisional restorations.

Standardized cavity Preparation:

In order to standardize the MOD cavity preparation to receive Onlay restoration, the teeth were prepared by computer numerically controlled CNC milling machine where the amount of reduction was evaluated via a putty impression taken before the preparation. Preparation of the occlusal cavity was started in the central fossa of the occlusal surface to a depth of 3mm. The mesio-distal length of the occlusal cavity was 6mm. The bucco-lingual width was 4mm which corresponded to about 1/3 of the intercuspal width. The width of the gingival seat was 2mm mesiodistally at the cervical part. The gingival seat was kept 1mm above the cervical line. The buccal and lingual cusps were reduced 2mm. Finally, Provisional restorations were fabricated for each preparation and their thickness was measured using a caliper to verify the amount of reduction.

Fabrication of ceramic onlay restoration:

Fabrication of onlay restoration from the Nano-ceramic hybrid and composite blocks:

Each prepared tooth was sprayed with a special light reflecting powder to improve scanning quality, the sample was fixed using super glue on the shifting plate of the in-Lab scanner "Prime Scan". The restorations were designed and adjusted to the proper shape, size dimensions by Cerec in-Lab CAD/CAM, using Cerec Primemill software system. The 3-D virtual models displayed on the design window were then used to design and modeling the restorations. The onlay thickness was checked by the software to standardize the thickness of all samples. The final restoration was then inspected for any correction and the sprue location was selected. After milling the restorations, all specimens underwent polishing according to the manufacturer's recommendations using all finishing and polishing kit (Ceramage, Shofu).

Fabrication of onlay restoration from the IPS e.max Press ceramic:

To overcome the problem of variant of manually fabricated restoration, the waxing up step was fabricated by using machinable CAD/CAM Wax Discs (eg: CAD wax). Each model (Prepared tooth) was sprayed with a special reflecting powder, and then the model with the stone base was secured to the model holder of the scanner with the aid of screws. The restoration was designed and adjusted to the proper shape, size dimensions. The cement space was set to 60μm for each restoration, and it was omitted at the margins of the preparation for about 60μm in order to ensure perfect adaptation according to the manufacturer's instructions.

The milling process was performed on both sides of the wax blank. A wax sprue was attached directly to the wax-ups and fixed on the ring base of the ring gauge. The investment was mixed with its liquid for 1 minute under vacuum, according to the manufacturer's instructions and poured on the CAD wax ups samples within the ring gauge. The investment ring was preheated without the ingot in a conventional preheating furnace (KaVo Type 5636, KaVo AG, D) beginning at room temperature and increasing to 850°C. The investment cylinder was separated, using a separating disc to create a predetermined breaking point. Subsequently they were cleaned in Invex liquid (Ivoclar-Vivadent AG, Schaan, and FL) in an ultrasonic unit for 10 minutes, rinsed with water and dried. Two glazing procedures took place in Programat P100 with Empress Universal Glasur D64847.

Surface treatment of the nano-ceramic hybrid composite and the reinforced composite Onlay restoration

The surface of the prepared sections were treated with Aquacare® system using 29 μm silica coated alumina powder followed by cleaning by ultrasonic cleansing unit. A thin layer of All bond Universal adhesive was then applied, rubbed in for 20 seconds, air thinned for 10 seconds, and light cured for 20 seconds.

Surface treatment of the ceramic Onlay restoration

The fitting surfaces of all ceramic onlay restorations were treated as follows:

Etching with Hydrofluoric acid:

The inner surfaces of the restorations of onlay ceramic restorations were etched using 9.5% hydrofluoric acid gel (IPS Ceramic Refill) according to the manufacturer instructions for 20 seconds. The ceramic onlay restorations were then washed thoroughly with air/water spray for 30 seconds. They were then dried using compressed air

Application of silane coupling agent

All onlay restorations were primed for resin onto their inner surface using a silane coupling agent (Pre-Hydrolyzed Silane Primer) for 60 seconds, then air dried before cementation. A thin layer of All bond Universal adhesive was then applied, rubbed in for 20 seconds, air thinned for 10 seconds, and light cured for 20 seconds.

Surface treatment of prepared tooth surface:

A- Acid etching of prepared teeth:

The prepared surfaces of all teeth samples were acid etched using 37 % phosphoric acid etching gel (Total-Etch) for 15-20 seconds, rinsed by air/water for another 20 seconds, then dried with air spray.

B- Application of the bonding agent:

All bond Universal Light-Cured Dental Adhesive (BISCO, USA) was applied for 20 seconds with a micro-brush on the etched surfaces of all teeth. The adhesive was thinned by air-syringe and light cured for 20 seconds.

Cementation of the onlays

A thin layer of Theracem resin cement: (BISCO, USA) was applied on the fitting surface of the Onlay restoration. Which was then placed in position with gentle finger pressure on the corresponding tooth and placed in the cementing device. Each onlay restoration was seated on its corresponding tooth under static pressure of 1Kg for 5 minutes. Excess cement was removed immediately with a micro brush and light cured for 20 seconds from all aspects. The exposed margins were covered with glycerin gel as recommended by manufacturer as air block material and then recured to avoid oxygen inhibition and ensures the complete polymerization.

Thermocycling:

All samples were subjected to thermocycling between 5C^{o} to 55C^{o} in water bath for a total of 5000 cycle with 10 seconds dwell time at each bath using thermocycling device.

Outcome Assessment:

Vertical marginal gap distance measurement:

The marginal gap distance between the outer margins of each Onlay and the margin of prepared tooth in a vertical direction was captured by CCD digital camera mounted on a stereo microscope.

The assessment criteria were defined as follows:

1. Perfect margin. The two adjoining surfaces show no interruption of the continuous margin and merge into each other without any difference in level.
2. Marginal gap. The two adjoining surfaces show slight imperfections with interruptions in continuity, a clearly visible loss of adhesion was described as a gap.

Fracture Resistance Testing

All samples were individually mounted on a computer-controlled materials testing machine (Instron Industrial Products, Norwood, MA, USA) with a load cell of 5 kN and data were recorded using computer software (Instron® Bluehill Lite Software).

Statistical analysis

Data was analyzed using Medcalc software, version 22 for windows (MedCalc Software Ltd, Ostend, Belgium). Data was explored for normality using Kolmogrov Smirnov test and Shapiro Wilk test. Continuous data showed normal distribution and was described using mean and standard deviation. Comparison between continuous data was performed using the one-way ANOVA test followed by Tukey-Kramer post-hoc test. A P value less than or equal to 0.05 was considered statistically significant and all tests were two tailed.

RESULTS

Fracture Resistance

Intergroup comparison has shown no statistically significant difference between the three materials ($P = 0.8181$). The lowest fracture resistance was within Crios, while the highest fracture resistance was within Grandio with no statistically significant difference between them, Emax has shown intermediate fracture resistance, which was not statistically different from Crios and Grandio ($P > 0.05$).

Table (1): Mean and SD of fracture resistance for different block materials:

	Mean	SD
Crios	2447.75	14.6233
Grandio	2571.5	11.5138
IPS-EMax	2477.08	20.3552
P value	P = 0.818	

Marginal gap

Intergroup comparison has shown statistically significant difference between the three materials ($P < 0.001$). The lowest marginal gap was within IPS Emax, while the highest marginal gap was within Grandio with statistically significant difference between them, Crios has shown intermediate gap distance, which was not statistically different from Grandio, but was statistically higher than Emax.

Table (2) Mean and SD of marginal gap for different block materials:

	Mean	SD
Crios	6.0992b	0.2827
Grandio	6.3650b	0.4738
IPS-EMax	5.2183a	0.2733
P value	P < 0.001*	

Means that do not share the same letter are statistically significant, * denotes statistically significant

DISCUSSION

This in-vitro test has been utilized to examine the properties of materials, providing insights into their potential clinical performance. Determining these properties is the initial step in understanding the behavior of restorative materials. Generally, ceramic inlays and onlays are considered clinically acceptable alternatives to cast gold restorations and amalgam fillings for extensively damaged teeth. However, failures primarily occur due to fractures or marginal leakage (Krug et al, 2024). This study evaluated the reliability of posterior all-ceramic partial coverage restorations (PCR) made from various materials and fabrication techniques, including IPS e.max Press, nano-ceramic hybrid Grandio blocks, and reinforced composite BRILLIANT Crios blocks using CAD/CAM. The restorations were tested under standardized and optimized conditions. Load-to-failure tests were performed to compare the fracture resistance of different PCRs after thermocycling. The findings of this study indicated that the fracture resistance of the used materials to fabricate onlay restorations in MOD cavities of molars are with no significant difference. Therefore, the null hypothesis tested was accepted. On the other hand, the null hypothesis concerning the marginal gap was rejected as there was a significant difference between different tested materials.

Fracture resistance results

Several factors influence the in vitro fracture load of esthetic restorations, including the material's microstructure, the fabrication technique, the ceramic surface finish, and the luting method (Keshvad A et al, 2011). Other significant factors include storage conditions, the shape of the metal rod, and the direction and location of load application (Attia A et al, 2004)

Regarding the material's composition, the highest fracture resistance observed in Grandio blocks can be attributed to their nano-ceramic hybrid composition, which combines the strength of ceramics with the flexibility of resin. This hybrid structure may enhance the material's ability to withstand higher loads without fracturing (Mertsöz et al, 2023) while Crios blocks showed the least fracture resistance, this could be due to their reinforced composite nature which renders them the weakest material used in terms of fracture resistance (A., Nassar et al, 2024). In addition to the intermediate fracture resistance of IPS e.max Press is likely due to its lithium disilicate ceramic composition, known for its high strength and durability. However, it may not be as flexible as hybrid materials, which could explain its position between Grandio and Crios (Kotb Salem et al, 2019). However, the lack of significant difference between the materials indicates that all three can be considered reliable options for posterior restorations, depending on specific clinical requirements. In accordance to the findings of our study the failure load for the IPS emax was ranged between (2707.05 - 3337.65 N with a mean= 2472.) this value was close to that of Saridag et al, 2013 (mean= 2646.7). and Bakeman et al, 2015 (mean=2505). In contrast to the results of our study, Stappert et al. (2007) found that CAD/CAM-produced partial coverage restorations exhibited a significantly higher fracture load compared to lithium disilicate glass ceramics, including IPS e.max Press, which were fabricated using hot pressing. In addition to Mertsöz, B. et al, 2023 who found that highest fracture resistance were found in BRILLIANT Crios. This could be explained by the difference in the restoration assessed, in addition to the difference in the prepartion techniques of the later study.

Marginal Gap Results

The initial marginal gap between tooth structure and a luting agent is often due to the polymerization contraction of the luting agent, even with a very thin layer (Stappert CFJ et al, 2008). Marginal quality deterioration is linked to cement wear, which can be accelerated by significant differences in the modulus of elasticity between ceramic and resin cement materials (Coelho Santos MJ et al, 2004).

The marginal gap for e.max press ceramic restorations was significantly lower than that of the Grandio and Crios restorations ($p < 0.001$). Both ceramic systems produced marginal gaps less than 100 μm, which is within the maximum clinically acceptable gap (Reich S et al, 2008). A marginal gap exceeding 100 μm can accelerate luting cement deterioration, with 100 μm being the maximum acceptable gap in clinical situations (Keshvad A et al, 2011).

Regarding the material composition, for IPS e.max Press**,** this material is known for its excellent marginal fit and high strength, which likely contributed to its lower marginal gap. Its superior properties make it less prone to issues like polymerization shrinkage and wear, leading to better marginal sealing (Elrashid AH et al, 2019).

The higher marginal gap in Grandio blocks could be attributed to their nano-ceramic hybrid composition, which may not provide the same level of marginal integrity as fully ceramic materials. The differences in modulus of elasticity between the ceramic and resin components might also contribute to marginal discrepancies (Hassan A et al, 2024).

Moreover, regarding reinforced composite, BRILLIANT Crios, it falls between the fully ceramic and hybrid materials in terms of marginal fit. Thus, its intermediate performance suggests that while it offers some advantages over hybrid materials, it does not match the precision of fully ceramic options like IPS e.max Press (Mohamed Elsharkawy, A. et al, 2021).

Furthermore, the differences in marginal gaps could also be attributed to the fabrication techniques used. IPS e.max Press is typically fabricated using a pressing technique that allows for precise control over the material's properties, resulting in better marginal adaptation while Grandio and BRILLIANT Crios blocks are often milled using CAD/CAM technology. These results are in accordance with Radek Mounajjed et al, 2016 as E.max lithium disilicate restorations created using the press technique exhibit significantly smaller marginal gaps compared to those produced with CAD techniques. The milling process, including factors like the diameter of the cutting tool and the accuracy of the milling machine, can affect the final fit. Larger cutting tools may not capture fine details, leading to larger marginal gaps (Saleh, Osama et al, 2016).

However, the results of our study were in contrast with Abo El Fadl A. et al, 2018 that stated The Emax CAD group exhibited significantly larger marginal gap values this could be attributed to the type of restoration used in the previous study.

Currently, there is no single perfect material for restorative dentistry, and the choice of material depends on the specific clinical situation. This selection should support contemporary treatment strategies that focus on conserving and preserving the remaining tooth tissues and structures.

CONCLUSIONS

Under the parameters of this study and based on the results the conclusions are:

1. Variations in marginal fit were observed for esthetic partial restorations produced using different manufacturing techniques. For instance, IPS e.max press ceramic demonstrated superior marginal sealing values compared to the nano-ceramic hybrid and the reinforced composite blocks.
2. The marginal discrepancies observed in all esthetic restorations in this study were within acceptable biological standards.
3. The fracture resistance of restorations in mutilated molars are significantly influenced by the type of material used.
4. All restorative blocks used in combination with adhesive technologies can lead to a more conservative, economic, and esthetic approach in the restoration of heavily compromised teeth.

RECOMMENDATIONS

1. Further studies are encouraged to assess the mode of failure of these restorations.
2. Long-term in vivo studies are necessary to assess the clinical outcomes of the onlay restorations made with different blocks and to determine if the results are applicable to clinical practice.

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