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BASIC RESEARCH:

Impact of Three Cementation Materials on the Fracture Strength of All-Ceramic CAD/CAM Overlay Restorations

Impacto de tres materiales de cementación en la resistencia a la fractura de restauraciones totalmente cerámicas CAD/CAM y restauraciones overlay

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ABSTRACT: To compare and assess the fracture strength of indirect overlay restorations bonded using various bonding techniques: sonically activated composite materials, preheated composite materials, and adhesive resin cement. The restorations were fabricated utilizing two distinct categories of all-ceramic CAD/CAM materials: reinforced resin composite blocks and lithium disilicate blocks. Depending on the CAD/CAM block type utilized for constructing the indirect overlay restorations, two main groups of 24 teeth each were created from the 48 human maxillary first premolar teeth that were ready for restorations. Group A consisted of indirect overlays made of lithium disilicate (IPS e.max CAD) blocks, whereas Group B used reinforced resin blocks (BRILLIANT Crios) for indirect overlays. subsequently according to the type of cement utilized in cementation. After the prepared teeth were scanned using the CEREC Omnicam digital intraoral scanner, indirect overlay restorations were designed utilizing CEREC Premium programme (version 4.4.4), and additional milling was carried out using the CEREC MC XL milling device. A computer-controlled universal testing machine (LARYEE, China) was then used to apply compressive axial loads to all cemented indirect overlay restorations at a crosshead speed of 0.5 mm/min till occurrence of fracture. A Student's t-test, LSD test, and one-way ANOVA test were utilized to analyze the data at a significance level of 0.05. This *in vitro* investigation revealed the greatest fracture strength mean value in the indirect overlays cemented with resin cement compared to other types of cement, regardless of the CAD/CAM block type. Depending on the findings of this research, regardless of the cement type, the mean fracture strength values of the indirect overlays made from both CAD/CAM blocks exceed the maximum biting force in the premolar area, indicating that both block types may be utilized clinically as overlay restorations in the premolar area.

KEYWORDS: Fracture strength; Resin cement; Lithium disilicate; CAD/CAM; Brilliant Crios; CAD/CAM.

RESUMEN: Comparar y evaluar la resistencia a la fractura de restauraciones indirectas tipo overlay cementadas mediante diversas técnicas de adhesión: materiales compuestos activados sónicamente, materiales compuestos precalentados y cemento resinoso adhesivo. Las restauraciones se fabricaron utilizando dos categorías distintas de materiales cerámicos totalmente estéticos para sistemas CAD/CAM: bloques de resina compuesta reforzada y bloques de disilicato de litio. Se utilizaron 48 primeros premolares superiores humanos, que fueron distribuidos en dos grupos principales de 24 dientes cada uno, según el tipo de bloque CAD/CAM empleado para la fabricación de las restauraciones tipo overlay indirectas. El Grupo A incluyó overlays fabricados con bloques de disilicato de litio (IPS e.max CAD), mientras que el Grupo B utilizó bloques de resina reforzada (BRILLIANT Crios). Posteriormente, cada grupo se subdividió según el tipo de cemento utilizado en la cementación. Tras el escaneo de los dientes preparados con el escáner intraoral digital CEREC Omnicam, las restauraciones tipo overlay se diseñaron utilizando el programa CEREC Premium (versión 4.4.4), y el fresado se realizó con el dispositivo CEREC MC XL. Luego, se aplicaron cargas axiales compresivas sobre todas las restauraciones cementadas mediante una máquina universal de pruebas controlada por computadora (LARYEE, China), a una velocidad de desplazamiento de 0.5 mm/min hasta que se produjo la fractura. Los datos se analizaron mediante pruebas t de Student, prueba LSD y ANOVA de una vía, con un nivel de significancia de 0.05. Esta investigación *in vitro* reveló que las restauraciones tipo overlay cementadas con cemento resinoso presentaron los valores medios más altos de resistencia a la fractura en comparación con otros tipos de cementación, independientemente del tipo de bloque CAD/CAM utilizado. Según los hallazgos de este estudio, independientemente del tipo de cemento empleado, los valores medios de resistencia a la fractura de las restauraciones tipo overlay fabricadas con ambos tipos de bloques CAD/CAM superan la fuerza máxima de mordida en la región premolar, lo que indica que ambos materiales pueden ser utilizados clínicamente como restauraciones tipo overlay en dicha región.

PALABRAS CLAVE: Resistencia a la fractura; Cemento de resina; Disilicato de litio; Brilliant Crios; Restauraciones CAD/CAM.

INTRODUCTION

In part, significant cultural and technological changes have been brought about by introducing adhesive techniques in restorative dentistry. The advancement of restorative materials and adhesive strategies has impacted posterior tooth restoration, significantly altering the treatment approach. In addition to aesthetic considerations, adhesive posterior restorations are necessary to repair deficient tooth structure and achieve bioeconomic benefits (1).

When a tooth is restored indirectly, the indirect restoration material is typically used to cover or replace the direct restorative material, extending the restoration's lifespan. The primary determinants include the material used in the indirect restoration being more resistant to wear, fracture, and discoloration; also, it provides a superior marginal seal (2).

CAD/CAM technology in dentistry is becoming more and more popular due to its advantages in processing time, standardization of manufacturing processes, savings of material, and the ability to predict restorations. When the CAD/CAM design approach is utilized, the steps number needed to develop the restoration is reduced in comparison to conventional processes. In dentistry, the use of CAD/CAM offers many advantages, including the use of data collection elements, a simple, non-damaging process for saving the impression and restoration, and the ability to save data on a computer, enabling sharing and communication for evaluation (3).

Manufacturers use fracture strength to compare, classify, rank, and advertise dental restorative materials. Since manufacturers target dentists, this may be based on their limited understanding of mechanics. Due to its apparent relationship to the material's load capacity, fracture strength is more straightforward to comprehend. The strength data of the materials depend on the material's microstructure (4).

Several factors impact the fracture strength of all-ceramic restorations. Factors linked to the restoration include the ceramic material composition, processing problems (microstructural flaws and defects), finishing and glazing (which affect the ceramic texture and roughness), and crown dimensions and geometry. Factors related to the cement materials include cement thickness, the adhesion mechanism, and the mechanical properties of the cement (mainly modulus of elasticity) (5).

Ceramic materials offer superior qualities to other materials in terms of biocompatibility, heat insulation, aesthetics, and inertness (6). However, due to their structural characteristics, they are more prone to fracture in oral environments. Compared to dental ceramics prepared in a lab, ceramic blocks in CAD/CAM systems tend to be more homogeneous and have fewer cracks and defects (7).

Over the years, indirect composite resin restorations with various mechanical characteristics have been developed. Compared to ceramic blocks, CAD/CAM composite resin blocks offer advantages: they cause less wear on opposing enamel, are less fragile (with fewer microcracks during the machining process), and show better marginal fitness (8, 9).

Therefore, to have a stable adhesive interface, a composite resin block with a high modulus of elasticity is used in the posterior; this, in turn, coincides with its function to replace the dentin (approximately 18.5 GPa) (10).

MATERIALS AND METHODS

The study protocol was approved by the Research Ethical Committee of Kerbala University, Iraq (2023-1104/DENT/302). The 48 human, non-carious first premolar teeth with two undamaged roots were extracted for orthodontic reasons from patients aged 18-22, collected from various health centers, and used in this study. Teeth were stored in deionized distilled water at room temperature. During all phases of the study, care was taken to avoid dehydration of the specimens. To prevent inter-examiner discrepancies and to ensure standardization, the preparation of all teeth was carried out by the same operator using a modified dental surveyor that was adjusted and used to prepare the occlusal surface and inter-proximal area of the tooth to maintain a clear tapering degree. Preparation was done in two steps: occlusal reduction and proximal reduction. For the occlusal part, the depth of reduction was determined by using a depth cut bur (No.300.2015). The tooth then received an occlusal reduction of 1.5 mm by using the Barrel-shaped trapezoid bur (No. D120470200), following the slopes of the cusps and the central groove. For the interproximal reduction, a slot preparation design of 1 mm depth was done by using flat-end diamond fissure bur (No. 8845KR314-018) held parallel to the long axis of the tooth to produce a round shoulder finishing line with a width of the gingival floor of the interproximal box of 1.5 mm with rounded inside angles. Based on the type of CAD/CAM block used to create the indirect overlay restorations, the 48 teeth were prepared for receiving the restorations and subsequently classified into two primary groups of 24 teeth each: Group A, with indirect overlays made from lithium disilicate blocks (IPS e.max CAD, Ivoclar Vivadent, Liechtenstein), and Group B, with indirect overlays made from reinforced resin blocks (BRILLIANT Crios, Coltene/Whaledent AG, Switzerland). Subgroups (A1, B1) used resin cement (RelyX Ultimate, 3M ESPE, USA); subgroups (A2, B2) used preheated composite (Z350 XT, 3M ESPE, USA); and subgroups (A3, B3) used sonically activated composite (Sonic Fill 2, Kerr Corp., USA). These divisions were depending on the type of cement utilized for cementation. The CEREC Omnicam digital device was utilized to scan the prepared teeth, and CEREC Premium programme (version 4.4.4) was used to design the indirect overlay restorations, with further milling conducted using the CEREC MC XL milling unit. Each indirect overlay restoration was cemented with the appropriate type of cement after performing surface treatment on the tooth and the internal overlay restoration, following the manufacturers' instructions.

For Group A, hydrofluoric acid (Ivoclar Vivadent, Liechtenstein, Etching gel <5%) was applied for 20 seconds based on the manufacturer's instructions to the internal surface of the indirect overlay, after which the etchant was removed by a suction tip. The internal surface was rinsed for 15 seconds with copious water, removing the debris and salts form on the porcelain surfaces owing to the use of the hydrofluoric acid, then the overlay were air-dried.. Utilizing a microbrush, a Single bond universal adhesive (3M ESPE, USA) was applied to the indirect overlay's interior surface for 20 seconds. This was followed by 5 seconds of gentle airflow and 10 seconds of light-curing with the VALO Cordless curing lamp (USA).

Group B's surface was treated for 10 seconds by sandblasting with 50 µm aluminum oxide at a distance of 10 mm (11). The purpose of sandblasting is to create a surface roughness that enhances mechanical retention and facilitates cleaning for bonding surface. Subsequently, the indirect overlay was kept in an ultrasonic cleaner for five minutes to eliminate any residual debris created from sandblasting according to the manufacturer's instructions. ONE COAT 7 UNIVERSAL was applied to the internal surface of the indirect restoration utilizing a disposable dental brush. After 20 seconds of surface rubbing and 5 seconds of gentle drying, light-curing was applied for 10 seconds. All groups' dental surfaces were treated with 37% N-ETCH phosphoric acid (Ivoclar Vivadent, Liechtenstein) for 15 seconds, as directed by the manufacturer, and then thoroughly rinsed for another 15 seconds. Excess water was suctioned without drying, leaving the preparation noticeably moist.

FOR CEMENTATION

1. Subgroups (A1, B1) used resin cement (RelyX Ultimate Clicker, 3M ESPE, USA). The catalyst paste and base were mixed into a homogeneous mass within 20 seconds, and the cavity walls and floor area were wetted with the RelyX Ultimate Clicker. The indirect overlay restoration was seated with finger pressure, followed by a vertical arm of the device delivering a load of 5 kg and light-curing for 20 seconds on the buccal and lingual surfaces(12).

2. Subgroups (A2, B2), once the heating device (Ena Heat, Micerium, Italy) reached 54°C, the Z350 XT capsule was heated for 15 minutes (13). The preheated composite was then placed into the prepared tooth using a composite gun (Dentsply Sirona, USA). Initial seating was performed with finger pressure, and final seating was achieved using a holding device. Extra cement was

eliminated with a sharp probe, and light-curing was applied for 20 seconds on the buccal and lingual surfaces.

3. Subgroups (A3, B3), the Sonic Fill 2 composite capsule was connected to a special Sonic Fill handpiece set to level 5 extrusion speed, which reduced the viscosity by up to 84%, increasing the composite's flowability, as per manufacturer instructions. The composite was then kept on the prepared tooth, and the indirect overlay was seated. The remaining steps followed the preheated composite protocol as mentioned above.

Following cementation, the fracture strength of the cemented indirect overlays composed of the two different CAD/CAM materials was evaluated using a single-load failure test. Applying a computer-controlled universal testing machine (LARYEE, China), all samples were compressed axially until they fractured at a crosshead speed of 0.5 mm/min. A 4 mm diameter stainless steel rod with a rounded end was attached to the test machine's loading arm, whereas the acrylic block of the tooth sample was attached to the test machine's base. The loading machine's computer automatically recorded each sample's greatest force in Newtons (N).

RESULTS

Table 1 displays the descriptive data for the two groups, which include the standard deviation, mean, maximum, and minimum fracture strength values in Newtons (N).

According to Table 1, the indirect overlay of Brilliant Crios, cemented with resin cement, exhibited the highest mean fracture strength. In contrast, another subgroup demonstrated the lowest mean value, using an indirect overlay made of lithium disilicate and cemented with a preheated composite. For comparison of fracture strength, an independent t-test was utilized between both groups with identical cement type at a significance level of 0.05, as revealed in Table 2.

Table 2 shows that a statistically significant variation in fracture strength ($p<0.01$) was observed between both groups within each cement type. A one-way ANOVA was utilized to compare the fracture strength between subgroups within each group at a significance level of 0.05, as presented in Table 3.

According to Table 3, a statistically marked variation ($p<0.05$) was noticed between subgroups fabricated from Emax, while a statistically highly marked variation ($p<0.01$) was seen between subgroups fabricated from the Brilliant Crios block. Furthermore, the LSD test was carried out to compare the impact of cement on the fracture strength within each group, at a significance level of 0.05. A subgroup in which the indirect overlay was fabricated from lithium disilicate and cemented with resin cement revealed a statistically significant variation ($p<0.05$) in contrary to other types of cement. A statistically highly marked variation ($p<0.01$) was revealed in a subgroup in which an indirect overlay was made from Brilliant Crios and cemented with resin cement, compared to that cemented with other types of cement. Moreover, regardless of the block type, the subgroups cemented with preheated composite demonstrated a statistically non-significant variation ($p>0.05$) in contrary to subgroups cemented with sonically activated composite. The fracture modes were visually inspected using a magnifying loupe (2.5) to assess the fracture mode based on Burke's classification (14) for both types of blocks cemented with three types of cement, as presented in Table 4.

According to Table 4, all samples from subgroups where the overlay was fabricated using lithium disilicate and resin block, cemented with resin cement, and which resin block was cemented with sonically activated composite, in addition to the most of other subgroups samples, demonstrated a severe fracture of the overlay and/or tooth (Code V). In contrast, only a few samples from subgroups where the overlay was fabricated using lithium disilicate cemented with preheated composite and sonically activated composite, as well as an overlay fabricated from a resin block cemented with preheated composite, demonstrated overlay fractures only (Codes II and IV). Finally, neither subgroup sample exhibited Code I or III fracture modes.

Table 1. Descriptive data of fracture strength by groups and subgroups in (N).

Block type	Subgroups	Minimum	Maximum	Mean	± SD
Lithium disilicate (IPS e.max CAD)	Adhesive resin cement	1350	1670	1580	111.739
	Preheated composite	1210	1610	1425	124.786
	Sonically activated composite	1230	1640	1437.500	131.122
Resin block (Brilliant Crios)	Adhesive resin cement	1560	1890	1752.500	107.935
	Preheated composite	1530	1690	1620	59.761
	Sonically activated composite	1540	1730	1626.250	58.294

Table 2. Independent t-test for comparison of the fracture strength between both groups with identical type of cement.

Subgroups	Block type	Block type	T	P-value
1	Lithium disilicate (IPS e.max CAD)	Resin block (Brilliant Crios)	3.141	0.007 HS
2	Lithium disilicate (IPS e.max CAD)	Resin block (Brilliant Crios)	3.986	0.001 HS
3	Lithium disilicate (IPS e.max CAD)	Resin block (Brilliant Crios)	3.720	0.002 HS

Table 3. A One-way ANOVA and LSD test for comparison of fracture strength between the different subgroups.

Block type	Subgroups Mean ±SD	Subgroups Mean ±SD	P-value*	P-value**
Lithium disilicate (IPS e.max CAD)	Adhesive resin cement 1580±111.793	Preheated composite 1425±124.786	0.035 S	0.020 S
		Sonically activated composite 1437.500±131.122		0.030 S
	Preheated composite 1425±124.786	Sonically activated composite 1437.500±131.122		0.841 NS
Resin block (Brilliant Crios)	Adhesive resin cement 1752.500±107.935	Preheated composite 1620±59.761	0.004 HS	0.003 HS
		Sonically activated composite 1626.250±58.294		0.004 HS
	Preheated composite 1620±59.761	Sonically activated composite 1626.250±58.294		0.875 NS

*One-way ANOVA test

**LSD test

Table 4. Mode of fracture of different subgroup.

Block type	Subgroups	Code I (%)	Code II (%)	Code III (%)	Code IV (%)	Code V (%)	Total
Lithium disilicate	Adhesive resin cement					8 (100%)	8 (100%)
	Preheated composite		2 (25%)			6 (75%)	8 (100%)
	Sonically activated composite		1 (12.5%)		2 (25%)	5 (62.5%)	8 (100%)
Resin block	Adhesive resin cement					8 (100%)	8 (100%)
	Preheated composite		2 (25%)			6 (75%)	8 (100%)
	Sonically activated composite					8 (100%)	8 (100%)

DISCUSSION

The crown for a vital maxillary premolar with a large coronal defect is not advisable as a treatment approach because it removes more sound structures, thereby weakening the remaining tooth structure. Thus, an indirect overlay with modified occlusal preparation is assumed to protect the restoration and supporting unit. It is highly recommended to minimize the effect of lateral forces, which, in turn, reduces the likelihood of fracture (15-18). Several variables influence the strength of all-ceramic restorations, including the features of the chosen substances, cementation, restoration design, and material thickness (19).

The mean fracture strength of both block types ranges from 1425 N to 1752.5 N, surpassing the maximum biting force in the premolar area of 450 N (20). This result may be due, in part, to enough preparation of tooth that meets the requirements for each material used in this test, resulting in sufficient material thickness to bear the applied load. Furthermore, this is due to the adhesive cementation technique utilized with appropriate surface preparation of various materials according to the manufacturer's specifications.

COMPARISON OF FRACTURE STRENGTH AMONG GROUPS

REINFORCE COMPOSITE RESIN BLOCK

Regardless of the type of cement used, this study clarified a statistically marked variation between both types of block. All subgroups exhibited higher fracture strength for the indirect overlay fabricated from the reinforced composite block than those fabricated from lithium disilicate. This difference may be directly attributable to variations in the mechanical characteristics, microstructural features, and chemical composition of these two all-ceramic CAD/CAM materials.

The indirect overlays made from reinforced composite have a high mean value of fracture strength, which may be due to the following reasons:

1. Reinforced composite has a comparatively low elastic modulus (10.3 GPa) similar to dentin (11-19 GPa). This characteristic allows more load to be absorbed by the composite restoration, resulting in less load being transmitted to the underlying tooth structures (21).

2. The reinforced composite adhesively bonds with the 3 types of cement to the tooth, creating a monoblock concept due to similar chemical compositions among all bonding materials, thus producing a strong bond (22).

3. The high fracture toughness of the reinforced composite allows the organic content to absorb chewing forces that can contribute to its toughening process (23).

It should be noted that the lower flexural strength of reinforced composite may not necessarily indicate lower fracture resistance. The proposed reasons could include this material's comparable resilience and modulus of elasticity to natural teeth (24). Our results partially align with those of Jassim and Majeed (2018), who studied the fracture strength of various CAD/CAM materials: zirconia (CEREC Zirconia, Dentsply Sirona), hybrid dental ceramic (VITA ENAMIC, VITA Zahnfabric), lithium disilicate (IPS e.max CAD, Ivoclar Vivadent), zirconia-reinforced lithium silicate (CELTRA DUO, Dentsply Sirona), and reinforced composite (BRILLIANT Crios, COLTENE). They stated that the reinforced composite (BRILLIANT Crios, COLTENE) exhibited higher fracture strength than lithium disilicate (IPS e.max CAD, Ivoclar Vivadent) (22).

LITHIUM DISILICATE (IPS E.MAX CAD, IVOCLAR VIVADENT)

The mean fracture strength value of lithium disilicate indirect overlay restorations was lower than that of reinforced composite restorations, with statistically significant and highly significant variations. A potential reason for this difference can be attributed to the great elastic modulus of lithium disilicate (95 GPa) compared to the elastic modulus of dentin (11-19 GPa). This mismatch in elastic modulus causes stress to accumulate in the restoration, with the inability of the restoration to deform plastically to the same degree as the underlying tooth, which ultimately leads to induced crack propagation in the restoration, compounded by the low toughness of the material (2.0-2.5 MPa m½) (25). Another reason relates to the differences in the chemical structure of the indirect overlay material, adhesive bonding agent, and luting cement, which resulted in the absence of the monoblock concept.

COMPARISON OF FRACTURE STRENGTH AMONG SUBGROUPS

Independent of the block type of CAD/CAM, indirect overlays cemented with resin cement show a statistically greatly significant variation from those cemented with sonically activated composite and preheated composite. The indirect overlay cemented with resin cement exhibited a higher mean fracture strength value (1752.5 N) than preheated composite and sonically activated composite materials (1620 N and 1626.25 N, respectively). The possible explanation for why indirect overlays cemented with resin cement have higher fracture strength could be due to:

1. The difference in the viscosity of the materials used for cementation: the better adaptation of overlays cemented with resin cement compared to those cemented with sonically activated composite and preheated composite, as found in the first part of the study. Goujat et al. (2019) stated in a systematic review that internal and marginal adaptation is significant for the longevity of indirect restorations (26). Proos et al. (2003) utilized finite-element analysis to study the effect of the thickness of the luting agent on stress development in the crown of the premolar tooth. They reported that an increase in film thickness results in a 3% increase in the porcelain tensile stresses when comparing adhesive resin cement at two thicknesses, 50 to 100 µm (27).

2. Lower filler content: According to manufacturers, resin cement has a decreased filler content of 67% by weight compared to

preheated composite (78.5% wt) and Sonic Fill 2 composite (83.5% wt). This lower filler content has been shown to improve dentin bonding strength compared to other types of cement with higher filler content. It has been noted that, despite the higher mechanical features of composites, the fracture strength was more remarkable in overlays cemented with resin cement. This suggests that better adaptation has a more significant effect on fracture strength than the mechanical features of the cement material. Kavut *et al*. (2019) found that a higher value of fracture strength was reported in feldspathic ceramic veneers cemented with resin cement with lower filler content (Multilink, 39.7%) compared to resin cement with higher filler content (Panavia F 2.0, 70.8%) (28).

CONCLUSIONS

The following results might be determined within the parameters of this in vitro investigation:

1. The indirect overlay restorations made from both CAD/CAM materials exhibited a fracture strength that exceeded the maximum biting force in the premolar area, suggesting that both materials may be efficiently utilized clinically as indirect overlay restorations in the premolar, provided that appropriate tooth preparation and an adhesive cementation approach with suitable surface treatment are followed.

2. The indirect overlay made of Brilliant Crios and cemented with resin cement had the greatest mean fracture strength value, whereas the indirect overlay made of lithium disilicate and cemented with preheated composite had the lowest.

3. The microstructure and chemical composition of the CAD/CAM materials utilized for fabricating indirect overlay restorations significantly impacted their fracture strength.

4. Regarding adhesive partial restorations, the material's flexural strength cannot be considered in isolation; other material features, like fracture toughness and modulus of elasticity, must be considered. Because the total strength of the tooth restoration-cement complex is clinically significant, this is not a major problem given the inherent strength of all-ceramic restorations.

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