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FRACTURE RESISTANCE AND FAILURE MODE ANALYSIS OF BIOMIMETIC OVERLAYS CONSTRUCTED FROM DIFFERENT MACHINABLE BLOCKS AND SUBJECTED TO THERMO-DYNAMIC AGING. AN IN VITRO STUDY

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ABSTRACT

Purpose: To evaluate the fracture resistance and failure modes of biomimetic adhesive overlays constructed from two different types of machinable blocks after thermodynamic aging.

Materials and methods: Twenty-two sound maxillary premolars were prepared for adhesive overlays and randomly allocated into two groups (n=11) according to the material used for overlay construction: Group CT: advanced lithium disilicate with virgilite (CEREC Tessera), and Group BC: ceramic reinforced composite (Brilliant Crios) materials. Thermodynamic aging was done to all bonded samples followed by fracture resistance test. Modes of failure were evaluated with digital microscope at 10X magnification.

Results: Group *CT* recorded higher fracture mean values (1065.4 ±79.3) than group *BC* mean values (930.4 ±41.2). Failure mode distribution scores between the two material groups were statistically non- significant.

Conclusions: CEREC Tessera showed better fracture resistance than Brilliant Crios. Both materials showed similar percentages of catastrophic failure. The majority of samples in both groups exhibited repairable fractures.

KEYWORDS: Adhesive overlays, advanced lithium disilicate, ceramic reinforced composite, thermodynamic aging, fracture resistance.

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INTRODUCTION

Tooth response to masticatory forces and the resulting stress distribution mechanism is predominantly related to the remaining tooth structure. The main reasons for the success of biomimetic dentistry is combining minimal tooth structure cutting with advanced restorative materials and optimized bonding protocols. (1)

"Bio-rim" or "dome of compression" are the two terms used to refer to the tooth structure above the hight of contour. This part of the tooth is the one responsible for masticatory force distribution to the rest of the tooth structure. Recent studies showed that the preservation of this part of the tooth by using conservative indirect restoration designs and applying biomimetic protocols, resulted in higher fracture resistance and survival rates of the tooth-restoration unit in comparison to full coverage preparations especially in teeth with compromised structure as in mesio-occluso-distal cavities (MOD). (2-4)

Minimally invasive, biomimetic adhesive overlays have been recently investigated in many studies. The combination of conservative preparation designs, adhesive luting protocols and the presence of cuspal coverage were reported as the main reasons behind the success and long-term survival of these conservative restorations. Malament *et al*. reported 95.27% survival rate for lithium disilicate overlays in comparison to 96.7% survival in complete coverage with no statistically significant difference between them after 16.9 years of clinical service. (5,6)

One of the main reasons behind the failure of indirect restoration is fracture of the tooth-restoration complex. Previous studies reported that tooth and / or ceramic fractures represented 76.2% of the failure patterns followed by loss of retention 42.9% and recurrent caries due to leakage 28.6%. (7,8)

The evolution in current CAD/CAM materials has led to development of machinable blocks with inherent strength and fracture toughness, that enables the fabrication of thin, conservative restorations to be adhesively luted to the tooth structure. Advanced lithium disilicate glass ceramic is a new type of machinable blocks with strengthened structure. A dual microstructure of needle-like lithium disilicate and platelet-like lithium alumino silicate known as virgilite all embedded in zirconia-enriched glassy matrix contributed to the highest biaxial and flexural strength (700MPa) amongst glass ceramics group. (9)

As the search for the optimum indirect restorative material continue, more composite machinable blocks are introduced to the market. Ceramic-reinforced resin-based CAD/CAM materials have the ability to provide tooth structure biomimicry, optimum adhesion with adhesive luting agents, as well as high fracture resistance under dynamic loading. (10)

However, the performance of both newly introduced materials (advanced lithium disilicate and ceramic reinforced composite) in premolar indirect conservative restoration under dynamic loading was rarely investigated. Therefore, the aim of this study was to evaluate the fracture resistance and failure modes of biomimetic adhesive overlays constructed from two different types of machinable blocks (advanced lithium disilicate with virgilite and ceramic reinforced composite) after thermodynamic aging. The null hypotheses were that there would be no difference in the fracture resistance or failure modes between the two tested materials.

MATERIALS AND METHODS

This study protocol was registered and exempted by Institutional Review Board Organization, Faculty of Oral & Dental Medicine, Ahram Canadian University on 11/2/2024. Approval no.: IRB00012891≠98.

Sample size was calculated using G Power, version 3.1.9.7. A total of 22 samples (11 samples per group) was found to be sufficient to detect the difference between means with a power of 80% and a significance level (alpha) of 0.05 (two-tailed) at 95% confidence interval.[11]

Samples grouping and preparation:

A total of twenty-two intact, defect free, human maxillary premolars that were extracted for orthodontic reasons were obtained from the oral surgery department in Ahram Canadian University for this study. After removal of all calculus and debris with ultrasonic scaler, the teeth were inspected for cracks, caries or any surface defects with 4.0X surgical magnification loups and LED headlight (Univet, Italy). Digital caliper (Mitutoyo IP 65, Japan) was used for verification of similar dimensions in both bucco-lingual and mesio-distal aspects at the region of cementoenamel junction (CEJ) with maximum dimensional deviation of ±5%. All teeth were stored in 0.1% thymol solution for 24 hours followed by storage in distilled water till the study started.

In order to mimic clinical conditions, periodontal simulation was done by immersing the teeth roots in molten modelling wax, then, a dental surveyor was used for embedding the teeth into a custom-made plastic mold (20mm diameter and 15mm height) filled with self-cured acrylic resin in a vertical direction, at the same occlusal level and 2mm below CEJ. After initial resin polymerization, teeth were removed and both roots and mold were cleaned and dried. Super-light body, polyvinyl siloxane impression material (Elite HD+, Zhermack SpA, Italy) was injected into the tooth-space in the mold followed by teeth repositioning into their previously created acrylic sockets under steady finger pressure.

Prior to teeth preparation, a preoperative optical impression was obtained for all teeth samples using Omnicam intraoral scanner and Biogeneric Copy mode in CEREC 3D software Version 5.1.1 (Dentsply Sirona GmbH, Germany). This optical impression aimed to serve as baseline scan for digital checking of standardized preparation parameters afterwards.

Following morphology driven preparation design (MDPD)[12], a rounded end tapered diamond bur (Komet, Schaumburg, USA) mounted in computerized numerical control milling machine (CNC milling machine, Centroid, USA), was used to perform a standardized overlay reduction for all teeth. Anatomical occlusal reduction of 1.5 mm on the functioning cusp (palatal) and 1mm on the none-functioning cusp (buccal) guided by the fissure direction was first done. Internal axial walls of MOD cavity were prepared with divergence angle of 6° angle and smooth, rounded internal angles. Flat-end diamond bur was then used to prepare the 1mm wide interproximal butt-margin at a level 2mm coronal to the CEJ. Finally, round-end diamond bur was used to prepare hollow chamfer margin (bevelled margin) 0.8mm thick at the outer occluso-axial line angle. All preparations were finished with fine grit diamond burs (Komet, Schaumburg, USA).

Teeth samples were randomly allocated to two equal groups according to the CAD/CAM material used for biomimetic adhesive overlays construction:

Group CT: advanced Lithium disilicate with virgilite (ALD) (CEREC Tessera, Dentsply Sirona, USA) overlays (n=11).

Group BC: Ceramic reinforced composite Brilliant Crios (Coltene, Whalendent AG, Switzerland) overlays (n=11).

The CAD/CAM materials used for overlay fabrication in this study are presented in **Table (1)**.

TABLE (1) Materials used for overlay fabrication and their compositions

Type	Materials	Main Composition	Manufacturer	Lot no.
Advanced lithium disilicate	CEREC Tessera	Matrix: zirconia glass Crystals: lithium disilicate ($Li_2Si_2O^5$), lithium aluminium silicate "virgilite" ($Li_{0.5}Al_{0.5}Si_{2.5}O_6$) Inorganic pigments	Dentsply Sirona Inc, USA	16013947
Ceramic reinforced composite	Brilliant Crios	Matrix: cross-linked BisGMA, UDMA, TEGDMA Fillers: Barium glass (BaO) < 1.0 µ, amorphous silica (SiO_2) < 20 nm, aluminum oxide (Al_2O_3) Inorganic pigments: FeO, TiO_2	Coltene, Whalendent AG, Switzerland	107803

Biomimetic Adhesive Overlays Fabrication

All prepared samples were scanned with CEREC Omnicam intraoral scanner. Digital verification of standardized preparation parameters was performed by superimposition of both baseline and final scans on CEREC 3D software. A standardized design for 22 overlays was ensured by utilizing Copy & Mirror tool in CEREC 3D software- version 5.1.1, where a master scan for dento-form maxillary premolar is used for creating the occlusal morphology of all restorations. Overlays were designed with cuspal thickness of 1.5mm at the tip and 1mm at the fissure area. 50µm radial spacer was set to facilitate restoration seating with no discrepancies. [11]

4-axis wet grinding/milling machine MCXL (Dentsply Sirona GmbH, Germany) was used for milling of overlay restorations. Two different types of machinable blocks were used for the construction of overlays. Group CT; 11 overlays were milled from advanced lithium disilicate block (CEREC Tessera), while, in group BC; 11 overlays were milled from ceramic reinforced composite blocks (Brilliant Crios). All restorations were checked on their corresponding teeth under 4X magnification loups and LED headlight to ensure the absence of any cracks or margin chippings. CEREC Tessera overlays were glazed in porcelain furnace (Programat P310, Ivoclar Vivadent Inc., USA) following the manufacturers' parameters. For Brilliant Crios overlays, 2 step polishing protocol was done following the manufacturer recommendations using DIATECH diamond polishing system (Coltene, Whalendent AG, Switzerland).

For group CT, adhesive cementation was done following the manufacturer instructions starting with etching with 9.5% hydrofluoric acid (Bisco Porcelain Etchant, Bisco, USA) for 20 seconds followed by restoration rinsing and drying for 20 s. Porcelain primer (Bisco, USA) was applied to the fitting surface, left to react for 1 minute then air dried for 30 seconds. As for group BC, restoration surface treatment was done as recommended by the manufacturer. First, the fitting surface was sandblasted with 50µm aluminium oxide powder with 1.5 bar pressure at 1cm distance, followed by steam cleaning. A thin coat One Coat 7 Universal adhesive (Coltene, Whalendent AG, Switzerland) was applied to the fitting surface of BC overlays, left for 60 seconds then air thinned.

All prepared teeth surfaces were etched with phosphoric acid 37% (Etch-37, Bisco, USA). After rinsing and drying, all bond universal adhesive (BISCO, USA) was applied for 30 seconds then air thinned and light cured for 20 seconds. Overlays were bonded to their corresponding teeth samples using adhesive dual cured resin cement (BisCem, Bisco, USA), under 1 kg vertical constant load using a custom-made loading device. After complete removal of excess cement, 40 seconds light polymerization was done at all restoration surfaces. After 24 hours storage in distilled water, all samples were subjected to thermo-dynamic aging.

Thermodynamic aging:

Samples were subjected to thermodynamic aging in masticatory simulator (ROBOTA, Model ACH-09075DC-T, AD-Tech Technology CO., GERMANY), including both thermal and dynamic mechanical aging. Thermal aging at 5 °C and 55 °C for 5000 cycles was done simultaneously with a dynamic mechanical aging in both vertical and horizontal direction for 250,000 cycles under 50N occlusal loading at a frequency of 1.6HZ, simulating one year of clinical service. After completing the aging protocol, all samples were inspected under 4X magnification loups and LED headlights to detect any possible cracks or fractures. [13,14]

Fracture Resistance Testing

Computer controlled universal testing machine (Instron, model 3345, USA) was used for fracture resistance testing. Individual samples were fixated to the machine's lower compartment, while, a spherical-end stainless-steel rod with 5mm in diameter a cross-head speed of 1mm/min was utilized in the upper compartment to apply vertical load to the center of restoration. After checking proper contact between the tip and the restoration occlusal surface, tin foil of 0.2mm thickness was applied between the tip and restoration to avoid one-point stress concentration and to simulate food mass. Vertical load was applied till restoration fracture occurred and was recorded in Newton (N).

Failure mode analysis was performed by U500x USB Digital Microscope (Guangdong, China) with built-in camera at 10X magnification for selected. Failure modes were categorized into two main categories based on their repairability; repairable failure and catastrophic failure. For repairable failure; Mode I: represented repairable fracture involving restoration only, and Mode II: represented repairable fractures involving restoration and tooth above CEJ. Catastrophic failure (Mode III) represented non-repairable fracture involving tooth and restoration below CEJ. [15-17]

Statistical analysis

Results were analyzed using Graph Pad Instat (Graph Pad, Inc.) software for windows at a significance level of $P \leq 0.05$. Normality of data was checked using Kolmogorov-Smirnov test, which revealed normal data distribution. Student t-test was done for compared pairs. Chi square test was performed for failure mode analysis. Sample size (n=11) was large enough to detect large effect sizes for main effects and pair-wise comparisons, with the satisfactory level of power set at 80% and a 95% confidence level. Continuous variables were expressed as the mean and standard deviation.

RESULTS

Results for fracture resistance results (Mean ± SD) measured in Newton (N) as function of overlay material group after thermodynamic aging are presented in **Table (2)** and **Figure (1)**

Comparison between different material groups revealed a statistically significant difference in fracture resistance $p < 0.001$, effect size = 0.158. Group *CT* recorded higher fracture resistance mean values than group *BC* mean values as verified by unpaired t-test.

Failure mode

Distribution of failure mode scores (%) for the two tested materials are presented in **Table (3)** and **Figure (2).** Digital microscope images showing different modes of failure are presented in **Figure (3).**

Failures were predominantly repairable (mode-I and mode-II) in both groups. For group

CT, frequent distribution of failure modes showed 45.4% mode-I and 27.3% mode-II, both repairable fractures. While, catastrophic fractures (mode-III) were 27.3%. On the other hand, group *BC* recorded lower catastrophic fractures score of 18% (mode-III), while repairable fractures were predominantly mode-II 54.7% followed by mode-I 27.3%. The difference in failure mode distribution scores between the two material groups was statistically non- significant by Chi square test *(P = 0.4274)*.

TABLE (2) Comparison between fracture resistance as function of overlay material group after thermodynamic aging

Variable		*Mean*	*SD*	*95% CI*		*P value*	*Effect size (Partial eta squared)*
				Low	*High*		
Material	***CT***	*1065.4*	*79.3*	*980.7*	*1210*	*<0.001**	*0.158*
	BC	*930.4*	*41.2*	*856.3*	*970.1*		

ns; non-significant (P>0.05) ****; significant (P<0.05)***

TABLE (3) Frequent distribution of failure modes scores (%) for both groups

Variable		*Failure mode*						*Statistics*
		Repairable				*Catastrophic*		
		Mode I		*Mode II*		*Mode III*		
		N	*%*	*N*	*%*	*N*	*%*	*P value*
Material	***CT***	5	45.4	3	27.3	3	27.3	0.4274 ns
	BC	3	27.3	6	54.7	2	18	

ns; non-significant (P>0.05) ****; significant (P<0.05)***

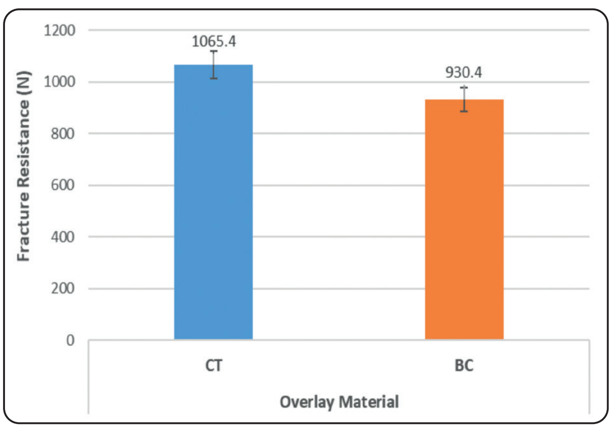

Fig. (1) Column chart showing fracture resistance mean values (N) as function of material group.

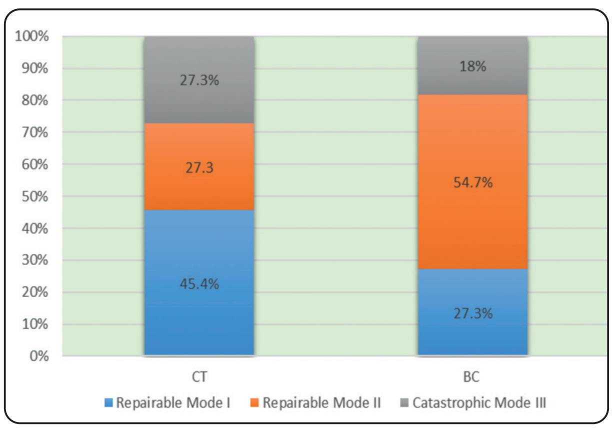

Fig. (2) Stacked column chart comparing the frequent distribution of failure modes scores for both groups.

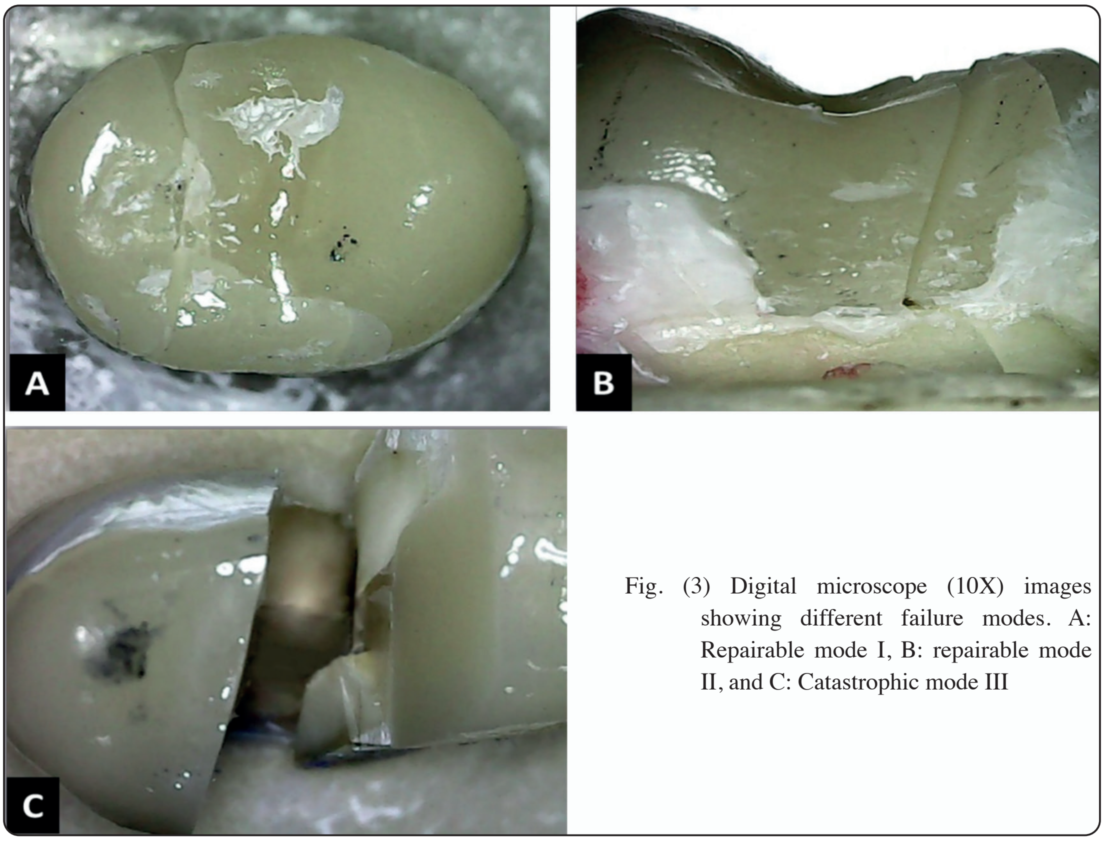

Fig. (3) Digital microscope (10X) images showing different failure modes. A: Repairable mode I, B: repairable mode II, and C: Catastrophic mode III

DISCUSSION

The first cause of failure of premolar indirect restorations is tooth/restoration fracture as was reported in many previous studies. [7,8] Thus, this study aimed to investigate the fracture resistance of biomimetic adhesive premolar overlays fabricated from two recent CAD/CAM blocks; advanced lithium disilicate with virgilite (CEREC Tessera) and ceramic reinforced composite (Brilliant Crios).

The results for fracture resistance in this study indicated statistically significant difference between the two investigated overlay materials. Hence, the first null hypothesis was rejected.

In this study, care was taken to simulate clinical situations as much as possible while ensuring proper standardization throughout the study. Selected teeth were verified for similar dimensions with digital caliper. A simulation of the periodontal ligament was done as it can influence the stress distribution within the tooth. [18] A CNC milling machine was used to perform standardized preparation in all study samples. [19] In addition, 3D digital analysis was performed for all the prepared samples by superimposition of pre and post preparation optical scans. This was followed by digital designing of all overlays with the same occlusal morphology and thickness. [20] Furthermore, thermodynamic aging protocol was utilized before fracture resistance testing where restorations were subjected to both vertical and horizontal forces along with thermal cycling for optimum mimicry of clinical settings. [13,14]

As maxillary premolars exhibit the highest fracture rates among posterior teeth due to their unsavoury anatomy and their location in the dental arch, they were the right subjects for this study where two new CAD/CAM materials were being investigated for providing the highest fracture resistance. [17,21] The mean fracture resistance scores for the two tested materials surpassed the normal (±450 MPa) and the parafunctional (±800 MPa) masticatory force range for premolar zone. [22] This indicates high reliability of the two tested materials. In addition, this also signifies the benefits of combining biomimetic preparation design (MDPD) with an optimum bonding protocol.[12] MDPD is a conservative biomimetic preparation design that allows for minimized tooth structure reduction while exposing large surface area of enamel through bevelled margin design (hollow chamfer) for an optimized bonding with adhesive resin cement. This facilitates stress distribution throughout tooth/restoration and improve the overall fracture resistance. [23,24]

The fracture resistance results in this study revealed that CEREC Tessera overlays had higher fracture resistance mean scores in comparison to Brilliant Crios overlays. These results agree with those reported by **Comba *et al*,** who reported statistically higher fracture resistance for lithium disilicate overlays than polymer-infiltrated ceramic ones.[25] They explained these findings by the difference between the two materials in terms of composition and microstructure, which influence each material flexural strength and fracture toughness. In this study CEREC Tessera was used which is an advanced lithium disilicate ceramic with flexural strength of 700MPa that even exceeds the range for lithium disilicate. The presence of dual microstructure as well as the introduction of platelet shaped virgilite crystals which has the ability to act as crack deflector may be responsible for the high fracture resistance in CT group in comparison to BC group. These results also agree with other studies that reported high fracture resistance of lithium disilicate partial coverage restorations compared to others fabricated from hybrid composite ceramics. [26-28]

Conversely, our results disagree with those by Rizk *et al,* who reported high fracture resistance for Brilliant Crios occlusal veneers than those fabricated from CEREC Tessera in 0.9mm and 0.6mm thickness. They explained these findings by the presence of similarity in composition between block material and adhesive resin cement, which improved the bonding and overall fracture resistance. [29] In addition, our results also disagree with those by another study that reported higher fracture resistance in Brilliant Crios occlusal veneers in comparison to e-max CAD and Vita enamic. [30] While these previous studies seem similar to ours, this controversy in results could be attributed to the differences in the restoration design. In our study, premolar overlays were investigated while other studies evaluated occlusal veneers. The presence of intracoronal cavity as well as MOD design can affect the bonding quality and the fracture resistance of the restoration. [17,31] Additionally, the bonding substrate in our study was natural teeth, while in other studies it was epoxy resin dies.[15] Furthermore, the presence of large surface area of enamel that was provided by bevelled (hollow chamfer) margin design when combined with the good adhesive qualities of acid etched and silanated advanced lithium disilicate might explain the marked improvement in the stress distribution at the tooth/restoration interface.[32]

With regard to failure mode analysis, statistically non-significant difference was found between the two tested material, although, group BC showed lower scores of catastrophic fractures. This could be attributed to the similarity in modulus of elasticity between BC and natural dentine as well as the resilient nature of ceramic reinforced composite. These features offer a better distribution of masticatory forces than in rigid glass ceramics where either cohesive ceramic fracture or catastrophic fracture of both tooth and restoration are dominant. [33] Moreover, mode II repairable fractures were more dominant in BC group, which indicates a stress induced parallel plastic deformation that occurs simultaneously in both restoration and supporting tooth leading to the fracture of restoration-tooth complex. [34,35]

However, as the two tested materials survived thermodynamic aging and when static load to fracture was applied both materials exceeded the normal masticatory force range, this indicates that both overlay materials are reliable under physiologic masticatory forces. Although in case of loading that exceeds the functional limits, advanced lithium disilicate materials seems to be more valid. Facenda *et al,* reported similar findings in a previous comprehensive review. [36]

From a clinical stand point, ceramic reinforced indirect composite material has better handling qualities in comparison to glass ceramic materials as the final crystallization/glazing step is eliminated which reduces the chairside time. [33]

One of the limitations of this study is still the in vitro design. With all efforts done to simulate the clinical situation with thermodynamic aging, oral cavity has its unique complex environment that may have different effect on restoration fracture behaviour and longevity. Further in vitro and randomized clinical studies are required to investigate these materials with different overlay designs and in different areas in the oral cavity.

CONCLUSIONS

Within the limitations of this in vitro study, the following can be concluded:

1. Advanced lithium disilicate ceramic material showed better fracture resistance than ceramic reinforced composite material.
2. Both tested materials demonstrated optimal survival under thermodynamic aging and fracture resistance scores that surpassed the normal and parafunctional limits for premolars.
3. Both materials showed similar percentages of catastrophic failure. The majority of samples in both groups exhibited repairable fractures.

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