Vol: 8 Issue: 2

EDJ

Evaluation of Fracture Resistance of Indirect Ceramic Overlay Used with Different Fiber-incorporated Base Materials

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ABSTRACT

Background and Objectives: Adhesive ceramic overlay restorations have become a popular, conservative alternative to full-coverage crowns, with Computer-aided design and Computer-aided Manufacture technology improving fabrication efficiency. Advances in 3D- printing show promise in replacing milled restorations. In addition to the overlay material, the base material plays a critical role in restoration performance. Current study investigates the fracture resistance of fiber-reinforced core materials with various indirect restorations and examines their correlation in failure modes and fracture behavior.

Methodology: This in vitro study was conducted at Hawler Medical University / Erbil in November 2024. 100 freshly extracted maxillary premolars were included in the study. Following Mesio-Occlusal-Distal cavity preparations, teeth were restored using a range of fiberreinforced base and overlay restorative materials. Fracture resistance was evaluated using a universal testing machine at a rate of 1 mm/min, and failure mode were examined using a stereomicroscope. Statistical analysis was conducted using one-way ANOVA and the Tukey test.

Results: The study showed that zirconium and Emax overlays had significantly higher fracture resistance than indirect composite overlays, with no notable difference in resistance between the various base materials (Short fiber-reinforced composite, Polyethylene fiber core, Particulate filled composite) within the zirconium and Emax groups. While indirect composite overlay demonstrated low fracture resistance values, it exhibited the lowest tooth fracture rate compared to other restorative groups. From all of the analyzed groups, Emax+ Polyethylene ribbond core, Zirconium+ Polyethylene fiber core, Emax+ Particulate filled composite) groups showed the most promising fracture behavior and improved fracture resistance.

Conclusion: Materials with higher fracture resistance often exhibit unfavorable or catastrophic fracture patterns, whereas materials with lower fracture resistance present more favorable and repairable failure modes.

Keywords: 3D printed overlay, Fiber-reinforced restoration, Zirconia overlay, Fracture resistance.

Article Information

Submission Date: 4/5/2025
Revision date: 15/7/2025
Acceptance date: 17/7/2025
Publishing date: Dec 2025

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DOI: doi.org/10.15218/edj.2025.18

INTRODUCTION

In clinical dentistry, managing posterior teeth with considerable crown degradation is often essential. Numerous minimally invasive treatment alternatives are now accessible owing to recent advancements in adhesive dentistry. The maintenance of the residual dental structure is seen as a crucial requirement that must be met when considering alternative treatments to reinforce the restoration.

Indirect ceramic overlay restorations have been employed as alternatives to full-coverage restorations to conserve healthy tooth structure. Contemporary materials enable the manufacturing of ceramic fixed prosthesis by Computer-aided design and Computer-aided Manufacture technology (CAD/CAM), as opposed to the conventional hand-layering technique.[1]

Full-ceramic restorations have several drawbacks, however these drawbacks include their intrinsic brittleness and elevated cost relative to alternative solutions, necessitation of greater tooth preparation, potential abrasion of adjacent teeth, and an extended chairside duration owing to the complex bonding process.[2]

The advances of stronger ceramics enables the creation of thinner, more conservative restorations to satisfy posterior load demands. Lithium disilicate glass ceramics are designed for partial coverage restorations and provide improved fracture resistance. Zirconia (ZRO2), the most robust of contemporary dental ceramics, occupies a distinctive position among metal-oxides owing to its superior mechanical properties, exhibiting a flexural strength of 800-1200 MPa, which satisfies the physical requirements for load-supporting posterior restorations in patients with minimal occlusal clearance. When adequately finished and polished, it also leads to less attrition of the opposing dentition.[3]

Recently, an additive manufacturing process employing 3D-printing technology, which facilitates the fabrication of items by the sequential addition and fusion of layers of material, has gained favor in dentistry.[4,5] The nascent implementation of this technology in dentistry is underscored by inconsistent findings, particularly regarding the mechanical characteristics, dimensional precision, and fit of 3D-printed materials as permanent restorations. It is essential to evaluate if materials are intended for transient use, necessitating compliance with Class I biocompatibility, or permanent materials, which demand adherence to Class IIa biocompatibility standards for intraoral application and long-term stability .[6–8]

Resin composite restorations may be more economical alternative to total ceramic restorations. Composites are somewhat easier to fabricate than ceramics and may cause less abrasion to opposing teeth. To mitigate issues associated with shrinkage stress and polymerization kinetics, laboratory fabricated indirect composite restorations are recommended for large cavities. Those restorations enhance precise production of the exact tooth morphology.[1,9,10]

Many studies aimed to find ways for strengthening significant composite restorations and the residual tooth structure. Short fiber-reinforced composite (SFC) is a technique used to let direct resin composite be applied in challenging clinical conditions.[11,12] Short glass fibers help to improve the resistance of the filler structure against crack propagation. SFRCs efficiently function as a foundational material for overlays in extensive posterior cavities, augmenting resistance to restorative fractures through their crack-stopping capability, hence extending the durability of dental restorations. The biomimetic strategy of employing SFRCs as dentin substitutes is advocated for extensive cavities, hence improving the durability of restorations. 13–16 On the other hand, polyethylene ribbond fibers (PRF)—introduced in the early 1990s and under research for their various uses—improve the flexural strength, stress resistance, and modulus of elasticity of composite resins when embedded in a resin matrix, so offering good aesthetic appeal as well as useful properties. Better mechanical qualities of PRF enable it to resist great load without breaking. Its adaptability increases its function as a "shock absorber," especially in high-stress locations, therefore lowering the likelihood of failure in restorations.[17,18,19]

To our knowledge, no comprehensive study has been performed on the use of SFC and PRF as structural support beneath restorations created with CAD/CAM technology and 3D-printed restorations. Although extensive information is available concerning the properties of SFC or veneering materials, the behavior of these materials in combination under stress remains poorly known.[20,21]

The aim of this work was to explore the impact of reinforced and particulate-filled composites on the fracture behavior of different indirect posterior overlays generated by both subtractive and additive milling techniques. The objective of the work is to evaluate the effect of polyethylene fiber-reinforced core (PFC) and SFC on the fracture resistance and failure patterns of many indirect overlay restorations.

METHODS

Study Design

This in vitro study was carried out in College of Dentistry, Hawler Medical University (HMU), Erbil City, Kurdistan Region, Iraq on November 1st, 2024. The study aimed to evaluate the fracture resistance of fiber-reinforced indirect overlay restorations.

The materials used in this study with their composition are listed in Table 1.

Table 1. The Composition of the materials used in the study

Material	Manufacturer	Composition
everX Flow (SFC) Bulk shade	GC Corp, Tokyo, Japan	Bis-EMA, TEGDMA, UDMA, short glass fiber (200–300 µm, Ø7 µm), barium glass (70 wt%)
Clearfil S3 Bond (One-step)	Kuraray, Tokyo, Japan	MDP, HEMA, bis-GMA, dl-Camphorquinone, water, ethanol, silanated colloidal silica
Clearfil AP-X	Kuraray, Tokyo, Japan	Barium glass, Silica, Colloidal silica, Silicon dioxide (71 vol.%, 0.1–15 µm), Bis-GMA, TEGDMA, photoinitiator
Clearfil Majesty Flow	Kuraray, Tokyo, Japan	Hydrophobic aromatic dimethacrylate, TEGDMA, camphorquinone, barium glass filler, silica filler (Filler Content: 81 wt.%)
Ivoclar LT Press Ingots	Ivoclar, Ellwangen, Germany	Lithium disilicate, SiO_2, Li_2O, K_2O, MgO, ZnO, Al_2O_3, P_2O_5, and other oxides
Crowntec	Sarmeco, Swiss	Esterification products of 4,4′-isopropylidiphenol, ethoxylated and 2-methylprop-2-enoic acid, initiators, inorganic silica fillers (30–50 wt.%, 0.7 µm)
Ribbond	Ribbond Inc., WA, USA	Polyethylene fibers
Condac 37	FGM, Brazil	37% Phosphoric acid
Porcelain Etch	Ultradent, USA	9% Hydrofluoric acid
Clear Ceramic Primer Plus	Kuraray, Tokyo, Japan	Ethanol, 3-MPS, 10-MDP

DOI: doi.org/10.15218/edj.2025.18

Freshly extracted sound maxillary premolars were collected from orthodontic clinics in Erbil, placed in 0.9% sodium chloride solution, and preserved at 37°C. The teeth were collected from patients aged between 15 and 25 years, a total of 100 premolar teeth, free of cracks, caries, or occlusal wear, were selected. The occlusal dimensions of the teeth were measured using a digital caliper (Mitutoyo, Japan), revealing mean values of 9.01 ± 0.55 mm buccolingually and 7.13 ± 0.47 mm mesiodistally.

Any tooth with visible cracks, restorations, and chipping were excluded from the study. Custom acrylic holders of 2.5 mm diameter were created, and the root surfaces of the teeth were dipped in melted wax to simulate the periodontal ligament space. The teeth were then embedded in polymethyl methacrylate resin. Laser aligner was utilized to ensure complete parallelism of the tooth inside the holder. After mounting, the teeth were prepared with MOD cavities the palatal cusps were completely removed, and the teeth were divided into six experimental groups, one negative control and three positive control groups Figure 1.

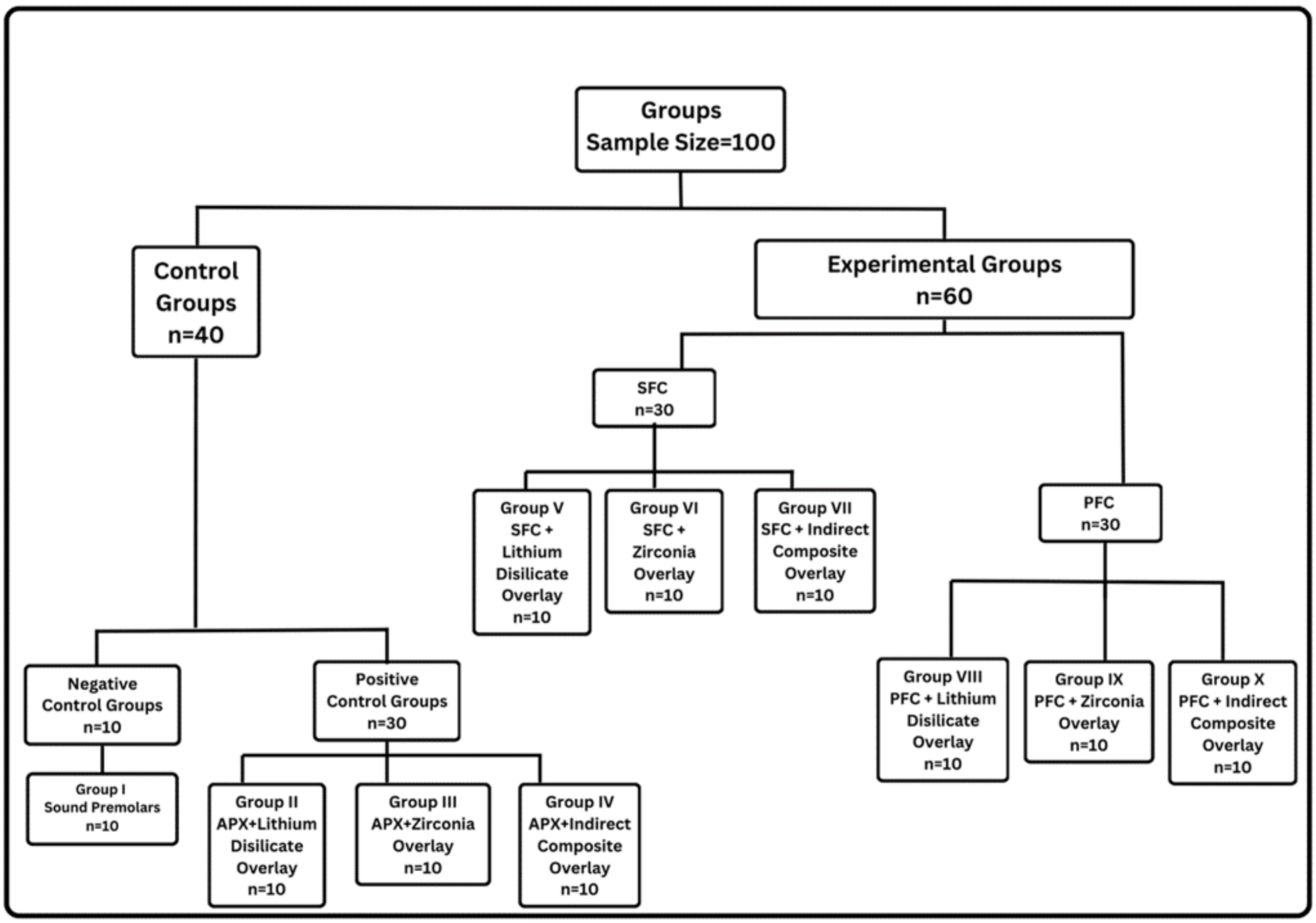

Figure 1. Distribution of the control and experimental group

Preparation and Restoration Techniques:

MOD cavities were prepared with a total depth of 5.0 mm from the cusp tip, with 3.0 mm buccal cusp width Figure 2 and a 1.0 mm enamel margin1,2. The preparations were performed using flat-ended (848KRS-018C, Hunterline) and (850KRS-018C, Hunterline) round-ended diamond burs under water cooling. After cavity preparation, selective acid etching for the enamel with 37% phosphoric acid was done (Condac37, Fgm, Brazil) for 10 seconds, followed by the application of a single-bottle universal bonding agent (Clearfil S3 Bond, Kuraray, Tokyo, Japan). The adhesive layer was then cured by LED light

cure Valo (Ultradent) for 10 seconds as per the manufacturer's instructions.
In the SFC group, EverX Flow Bulk (GC, Japan) was applied in a 1.5–2.0 mm thickness, measured with scaled periodontal probe and light-cured for 10 seconds at 1500 mW/cm² using a high-power LED (Valo, Ultradent, USA), with the curing tip positioned 1–2 mm from the surface. The PFC group involved applying a 0.5–1.0 mm layer of flowable composite (Clearfil Majesty Flow, Kuraray, Japan), followed by placement of a 3.0 mm wide polyethylene fiber (Ribbond THM) onto the flowable layer, adapted with Modeling Liquid (GC, Japan), and light-cured for 20 seconds. A 1.0 –1.5 mm layer of Clearfil Apx (Kuraray, Japan) was then added and cured for 20 seconds. The Apx group followed the same adhesive protocol, with a 1.5–2.0 mm layer of Clearfil Apx applied and light-cured for 20 seconds using the same LED unit.

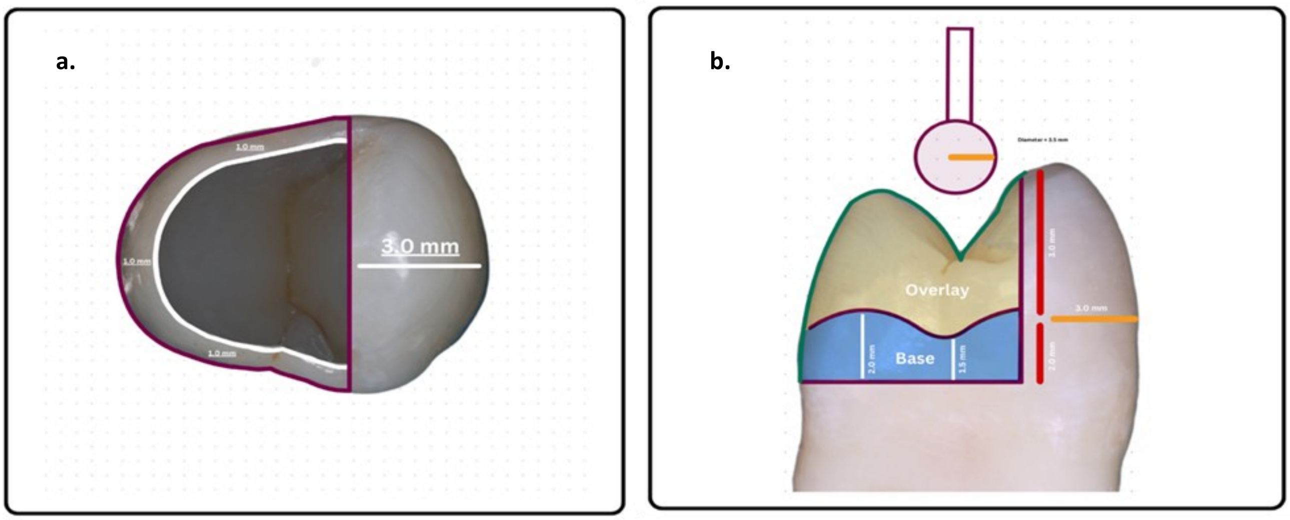

Figure 2. a. Cavity preparation design, b. restoration design

Indirect Restoration
After restoration of the sample teeth, leaving 3.0 mm space for the indirect overlay and 1.0 mm peripheral enamel, measured with scaled periodontal probe, any excess was prepared with high -speed turbine round-ended diamond burs (850KRS-018C, Hunterline) with water cooling, all samples were scanned with an intraoral scanner (Medit i900, Korea). The samples were digitally designed using Exocad software. Lithium disilicate overlays (Emax Press ,Ivoclar) and zirconia restorations (Katana STML, Noritake) were fabricated and sintered according to manufacturer guidelines. Additionally, 3D-printed restorations were fabricated using a resin 3D printer (Max X, Asiga) and using the permanent restoration resin (Crowntec, Sarmeco)
Each restoration was cemented following specific protocols for different materials: Lithium disilicate overlays were treated with hydrofluoric acid 9% (Porcelain Etch, Ultradent, USA) for 60 seconds and silane coupling agents were then applied (Clearfil ceramic primer, Kuraray, Japan). Zirconia overlays were sandblasted with alumina oxide particles (Al_2O_2) of 50 µm and treated with a 10-MDP based silane (Clearfil ceramic primer, Kuraray, Japan). 3D-printed restorations were similarly sandblasted with 110 µm Al_2O_2 under 0.2 MPa, cleaned, and treated inside an ultrasonic bath of alcohol for 2 minutes and steam dried, followed by coating the internal surface with a silane coupling agent (Clearfil ceramic primer, Kuraray, Japan). . Dual-cure self -adhesive resin cement (Panavia SA, Kuraray) was used to cement the restorations. The material was applied to the fitting overlay surface directly by the auto-mixing tip and fitted to the adherent surface of the tooth. The restorations were then light cured for an initial 5 seconds using an LED dental light cure (Valo, Ultradent, USA) at an intensity of 1500 mW/cm², then letting for a chemical cure of 5 minutes as per manufacturer instruction.

DOI: doi.org/10.15218/edj.2025.18

Fracture Load Test
After cementation, a quasi-static compressive load was applied using a universal testing machine (Max Series, ALFA, Turkey). A 3.5 mm metal ball was used to apply the load at a speed of 1mm/min between the ridges of the lingual and buccal cusps. . The device tip parallelism to the occlusal surface was ensured by the laser aligner for the tip to touch perpendicular to the occlusal surface. The restoration surfaces were covered by custom Ethylene Vinyl Acetate Copolymer, which increases friction between the metal head and the occlusal surface while preventing point stress concentration Figure 3. The loading curve was carefully monitored until the restoration fractured, as indicated by the final incline in the load–deflection curve.

Statistical Analysis
Data analysis was performed using SPSS version 23. The impact of different restorative techniques on the load-bearing resistance of the restorations was analyzed using ANOVA with a significance level of $p < 0.05$, followed by the Tukey test for pairwise comparisons.

Figure 3. Custom Ethylene Vinyl Acetate Copolymer coverage of the occlusal surface during the loading procedure

RESULTS
All of the samples were exposed to quasi-static load until failure. Table 1 displays the mean fracture load values of the restorations after load to failure test. The natural tooth group has an average fracture resistance value of 984.3 N ∓ 196.6 N. The fracture resistance of Indirect Composite Overlay (ICO) group with all different core materials was significantly lower than all other multilayer indirect restoration groups ($p > 0.05$). Although there was no substantial difference between the ICO overlay restored group and the natural tooth ($p < 0.05$). which mean ICO has failed to increase the fracture resistance of natural tooth, while hopefully the fracture resistance of the restored tooth is similar with the natural unprepared, unrestored tooth, as represented in Figure 4.
The ZrO_2 group with PFC had a fracture resistance of 1395N ∓ 348N, and with APX base had a fracture resistance of 1453N ∓ 441N. Both ZrO_2+PFC, and ZrO_2+APX had significantly higher fracture resistance values ($p > 0.05$) compared to the ICO overlay restored groups. While there was no statistically significant difference between both ZrO_2+PFC and ZrO_2+APX from the natural tooth and the Emax indirect restored overlay group combined with fiber and non-fiber reinforced base materials ($p < 0.05$). On the other hand, Indirect ZrO_2 overlay restored group combined with SFC base 1508N ∓ 446N was significantly different from the natural tooth and ICO indirect overlay restored group ($p < 0.05$). Emax overlay group reinforced with SFC had a mean fracture resistance value of 1349.9N ∓ 206.7N, with no significant difference with Natural tooth and ZrO_2 overlay restored group of all different base materials ($p < 0.05$), While there was significant difference with ICO overlay restored group.

Table 1. Mean and standard deviation of the fracture load values

Means					
C1	N	Mean	StDev	95% CI	
Natural	10	984.3	196.6	(778.3,	1190.4)
ICP+SFC	10	788.9	247.8	(582.8,	994.9)
ICP+PFC	10	559.2	108	(353.2,	765.2)
ICP+APX	10	667.4	206.4	(461.4,	873.5)
ZrO2+SFC	10	1508	446	(1302,	1714)
ZrO2+PFC	10	1395	348	(1189,	1601)
ZrO2+APX	10	1453	441	(1247,	1659)
Emx+SFC	10	1349.9	206.7	(1143.9,	1555.9)
Emx+PFC	10	1668	264.5	(1461.9,	1874.0)
Emx+APX	10	1520	542	(1314,	1726)

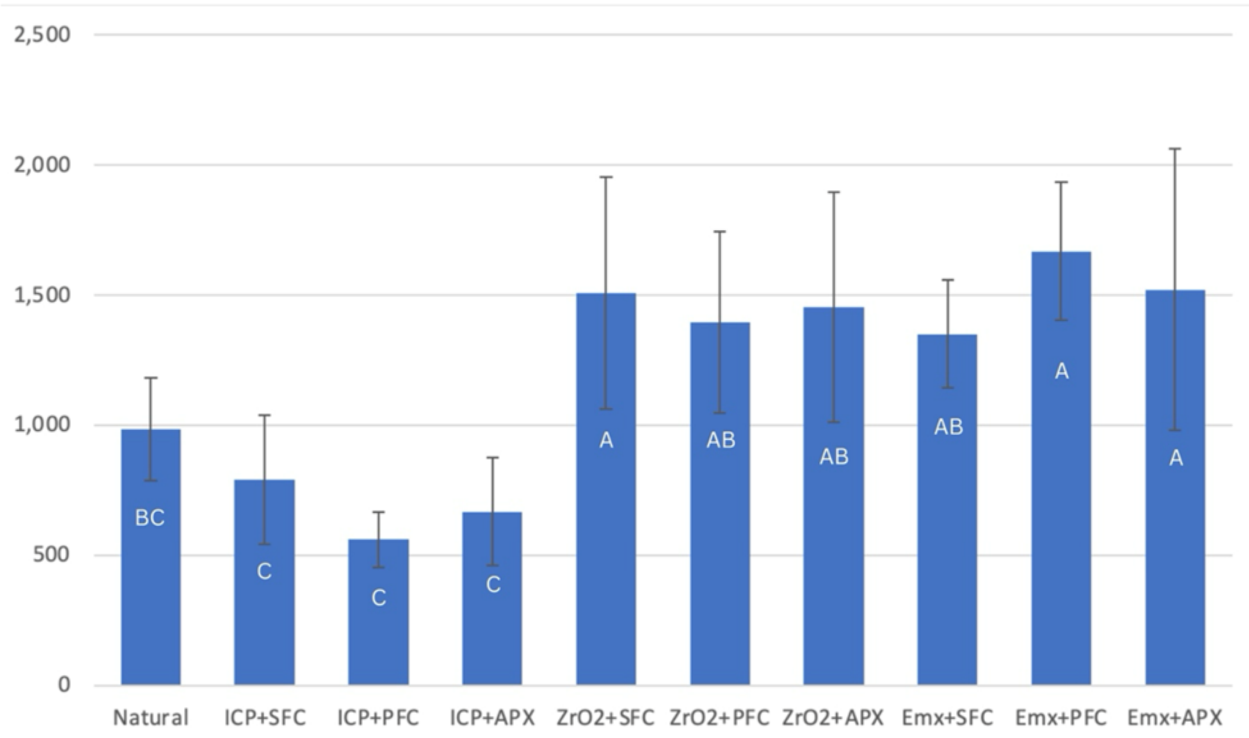

Figure 4. Average mean values of fracture resistance between different groups. The same letters inside the bars represent statistical non-significant difference ($p > 0.05$)

DOI: doi.org/10.15218/edj.2025.18

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Additionally, Samples restored with PFC and APX and Indirect Emax overlay restoration had high fracture values of 1668N ∓ 264.5 and 1520N ∓ 542N was significantly different from the natural tooth group and ICO restored group ($p > 0.05$). In average 90% of the ICO indirect overlay restoration groups combined with different base material have only fractured the restoration, and the tooth structure was left intact.

The ICO+SFC group had managed well under load, 100% of the failures were limited to fracture of the restoration only, %90 fracture of the overlay material, and %10 the fracture of Overlay and base material. On the other hand, 80% of the ICO overlays fractured when combined with PFC, and 20% led to tooth fracture. Additionally, in ICO+APX group, the tooth fracture rate was limited to 10% only, while %90 of the fractures were limited to the overlay restoration. Figure 5 demonstrates the exact percentage ratios of the failure type.

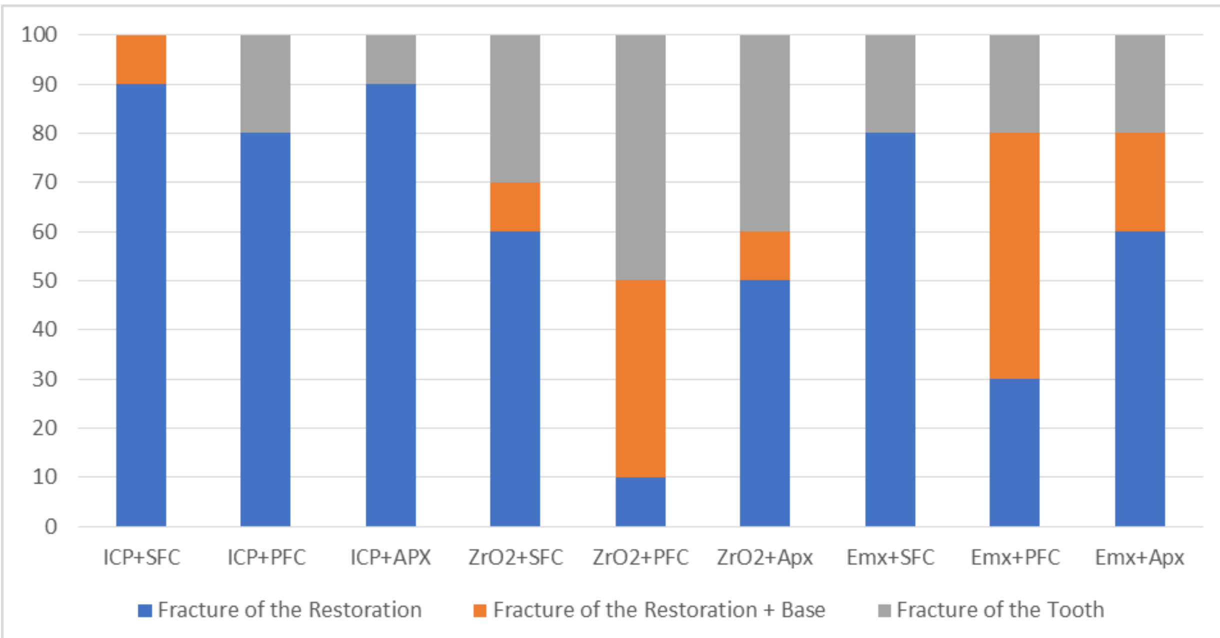

Figure 5. Percentage distribution of failure mode between different groups

The mean fracture rate of the tooth structure in the ZrO2 overlay group has been identified to be 40%. The highest tooth fracture rate was observed in PFC base material 50%, and the lowest tooth fracture rate with SFC base material was 30%, while APX base material has a tooth fracture rate of 40%, 70% of the ZrO2 overlay restorations has been fractured in SFC base material group, and only 10% has affected the base material, 60% of the fracture were only limited to the overlay restoration. While in the PFC base material 50% of the overlay structure were fractured, with 40% fracturing the PFC base material with overlay restoration. Additionally only 60% of the APX based indirect ZrO2 group has fractured the overlay restoration, with a rate of 10% APX base fracture. Lastly, the average fracture rate of the tooth in the Emax overlay group has been identified to be 20%, which is even in all different base material groups of SFC, PFC and APX. In Emax+SFC group the 80% of the fractures was limited to the overlay structure, with no fracture affecting the SFC base material at all. While in ZrO2+PFC group, 50% of the restoration fractures had fractured the base material, while only 30% of the fracture pattern has been limited to the overlay structure Figure 5. Furthermore, in Emax+APX group, while 80% of the fractures has been limited to the restoration only, only in 20% of the samples, the APX base has been fractured.

DISCUSSION

In this study, we evaluated how two different restorative strategies—fiber-reinforced and non-fiber-reinforced—affect the fracture resistance of large-modulus-diameter restorations. The investigation used three types of indirect restorations combined with three types of base materials in a bilayer configuration. The experimental design simulated clinical conditions involving extensive loss of tooth structure, The primary aim was to compare the fracture resistance of various indirect overlay restorations paired with different fiber-reinforced and non-fiber-reinforced base materials, as well as with natural tooth structure.

The present study demonstrated variability in the load-bearing performance of different restorative approaches. Our findings indicate that placing a thin (1–2 mm) layer of SFC as a base material did not produce a statistically significant difference in fracture resistance compared with restorations reinforced with PRF or those restored using APX particulate filler. These results align with previous research showing that incorporating SFC as a deep core material in posterior restorations does not necessarily enhance tooth fracture behavior.[3]

In this study, no significant difference was observed between the ZrO_2+SFC group and the e.max indirect overlay group ($p < 0.05$). This suggests that combining a ZrO_2 overlay with a short-fiber-reinforced base can provide load-bearing performance comparable to that of an e.max overlay restoration, while still offering increased fracture resistance relative to sound, unprepared natural teeth. The methodology employed in our study closely followed that of previous investigations that used a 1–2 mm SFC base beneath lithium disilicate indirect overlay restorations.[3–6]

When examining the differences among the ICO groups combined with SFC, PFC, and APX, the SFC group showed higher fracture resistance compared with the other base materials; however, these differences were not statistically significant. Likewise, no significant differences were found among the e.max groups combined with SFC, PFC, and ICO. Existing composite and ceramic materials remain inherently brittle—although they provide adequate strength, they lack sufficient toughness.[7] One major limitation of brittle restorative materials used to replace lost dentin is their substantially lower fracture toughness compared with natural dentin.[7]

When compared to the natural tooth structure, the Indirect Composite group has demonstrated reduced fracture resistance rates.[8] However, the natural tooth structure did not show any significant differences regarding fracture resistance. In the process of visualizing the fracture rates of all the different groups, it was discovered that the fracture resistance of ICO is significantly lower than the fracture resistance of all the other different restorative groups, regardless of the restorative base material that was utilized. The physical qualities of the 3D printed resin restorations are much poorer than those of the other indirect overlay restorations. This can be connected to the fact that these restorations are significantly inferior. Therefore, regardless of the composition of the material and the method of fabrication, zirconia and emax restorations are significantly more durable than 3D printed resin restorations. Although these materials are still undergoing development to become more robust, their fracture resistance is significantly lower due to the fact that they have microstructural differences and porosity issues.[9,10]

Although the findings of the present investigation differ from those reported by Amjadi M et al.[11], our results showed no significant difference in fracture resistance between the e.max and zirconia overlay groups. This contrasts with previous research, which reported that e.max—despite its inherent strength—tends to exhibit lower fracture resistance than zirconia, particularly in endocrown applications. Despite the constraints, however, specific considerations were taken into account during the load testing in order to guarantee that the applied load was parallel to the surface in the axial direction. Additionally, periodontal ligament (PDL) simulation has been performed because the PDL resembles the physiological tooth movement and influence on the fracture appearance. Previous research has demonstrated that the absence of PDL space resemblance during load-bearing tests caused fracture results that were almost twice as strong as those obtained from tests that included periodontium. On the other hands, Special consideration was applied to prevent spot stress concentration during force application , as the indirect restorations were covered by a custom final layer of Ethylene Vinyl Acetate Copolymer, which prevents slippage of the metal tip of universal testing

DOI: doi.org/10.15218/edj.2025.18

machine on load, while preventing stress concentration at one point.[15] While some study has employed tin foil of varying thicknesses, polyurethane sheets, and rubber sheets for comparable purposes, such materials were not custom fitted to the occlusal surface, other research has used these materials.
On the other hand, this in vitro study achieved a high level of standardization by regulating the dimensions of the tooth and preparation, along with the loading conditions and occlusal morphology throughout the experiment.

CONCLUSION

While ZrO_2 and Emax overlay restorations demonstrated the highest fracture resistance regardless of the base material, they also resulted in more catastrophic and less favorable fracture patterns, particularly in the ZrO_2 groups. Both short fiber composite (SFC) and polyethylene fiber-reinforced (PRF) bases performed comparably to particulate-filled composite (PFC) bases in terms of fracture resistance and failure behavior. Indirect composite overlays, though exhibiting the lowest fracture resistance overall, showed the most favorable and restorable fracture patterns—especially when combined with APX or SFC bases—and performed comparably to natural teeth in terms of fracture resistance. Among all groups, the Emax+PFC, ZrO2+PFC, and Emax+APX combinations provided the most balanced outcomes between resistance and repairability. Thus, while high-strength materials like zirconia offer durability, more conservative restorability may be achieved with fiber-reinforced or composite-based approaches.

ACKNOWLEDGEMENT

I would like to express my sincere gratitude to Dr. Sheban Farhad for his valuable support in the laboratory work. I am also thankful to Dr. Ranj Salai for his assistance with the statistical analysis. Special thanks are extended to BrightDent Company for their continuous support and for providing the materials used in this study.

CONFLICTS OF INTEREST

The authors declare that there are no conflicts of interest that could have influenced the design, conduct, analysis, or interpretation of the results of this study.

FUNDING

No funding was received for the conduct of this study.

AUTHORS' CONTRIBUTIONS

We confirm that the manuscript has been read and approved by all named authors. We also confirm that each author has the same contribution to the paper. We further confirm that the order of authors listed in the manuscript has been approved by all authors.

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