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MICROTENSILE BOND STRENGTH OF FLOWABLE RESIN COMPOSITE VERSUS GLASS IONOMER CEMENT RESTORATION ON CARIOUS PRIMARY DENTIN TREATED WITH SILVER DIAMINE FLUORIDE (AN IN VITRO STUDY)

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ABSTRACT

Background: Silver diamine fluoride (SDF) arrests caries but causes black staining and does not restore tooth structure. Combining SDF with restorative materials (SMART) technique combines SDF with restorative materials to address these limitations; however, the interaction between SDF and adhesives is not fully understood. The aim of this study to evaluate the effect of SDF on the microtensile bond strength of flowable resin composite (FRC) and glass ionomer cement (GIC) restoration to carious-affected primary dentin.

Materials and methods: Thirty extracted carious primary molars were randomly divided into two groups (n=15 each): Group I (FRC) and Group II (GIC) restoration. After caries removal, both groups received 38% SDF (3-minutes), rinsed for 30 s, and dried. Group I received etching (35% phosphoric acid, 15s), adhesive application, and incremental composite placement. Group II received a cavity conditioner (10s), GIC (light-cured 20s), and a final layer of Equia™ Coat. Specimens were subjected to 500 thermocycles, sectioned into 1×1 mm beam and tested for microtensile strength using a universal testing machine. Failure modes were examined microscopically. Statistical analysis included normality tests (Shapiro-Wilk, Kolmogorov tests) and comparative tests (T-test for quantitative data, Fisher's Exact test for qualitative data), with significance set at $p \leq 0.05$.

Results: Group I demonstrated significantly higher tensile strength compared to Group II. Regarding failure mode, the distribution difference between the two groups was statistically significant, indicating that Group I predominantly experienced mixed failures (100%), while Group II demonstrated a combination of mixed (53.3%), adhesive (20.0%), and cohesive (26.7%) failures.

Conclusions: Based on the findings of this study, it can be concluded that under the tested conditions, FRC demonstrated significantly higher micro-tensile bond strength (μTBS) compared to GIC restoration after applying SDF to demineralized dentin. Flowable resin composite may offer a more predictable bonding outcome with a more favourable failure mode.

Keywords*:* Microtensile bond strength; Flowable composite; Glass ionomer; Sliver diamine fluoride; Carious dentin.

INTRODUCTION

Dental caries remained a global health challenge for clinicians, despite the annual advancements and innovations in dental materials.[1] Although its incidence has declined in many nations in recent times, it continues to pose a substantial public health challenge. This complex, multifactorial disorder damages tooth integrity, resulting in tissue degradation caused by reduced mineralization, increased porosity, and modifications to collagen composition.[2]

Managing dental caries in primary teeth of young children present a significant challenge for dental practitioners.[3] The traditional drill-and-fill approach involves using a high-speed handpiece with a dental bur to excavate carious tissue from cavitated lesions, which often induces fear in children due to the noise and tactile sensations, leading to uncooperative behaviour and complicated dental procedures.[4] In cases of uncooperative paediatric patients, pharmacological management frequently necessitates sedation or general anaesthesia, that is associated with high treatment costs and potential health risks linked to hospitalizations. Such behavioural issues create a major obstacle in achieving effective restorative care for young children with dental caries.[5]

The evolution of minimally invasive dentistry (MID) has transformed the approach to dental caries management, particularly in young children. MID utilizes techniques such as silver diamine fluoride (SDF) and atraumatic restorative treatment (ART) to preserve tooth structure while minimizing patient psychological distress. These approaches play a critical role in improving children's oral health, especially in regions with limited access to conventional dental care.[6,7]

Silver diamine fluoride (SDF) is often termed a "silver-fluoride bullet" due to its dual capacity to arrest active dental caries and inhibit the formation of new carious lesions. This cost-effective treatment demonstrates high efficacy, leveraging fluoride's remineralizing properties and silver nitrate's antibacterial action. Its straightforward application makes it particularly advantageous for managing caries in very young or uncooperative children. Nonetheless, a notable limitation of SDF is the occurrence of black staining, which poses aesthetic concerns. Additionally, while SDF effectively stops caries progression, it does not restore the lost tooth structure or masticatory function, as it is a non-invasive approach that leaves carious lesions unfilled.[5,8]

The scientific literature remains inconclusive regarding the precise mechanism of action of SDF, though its anticaries efficacy is demonstrated by the characteristic black staining, which signifies arrested caries activity. To reduce discoloration, potassium iodide (KI) has been employed post-SDF application.[9] An additional strategy called silver-modified atraumatic restorative therapy (SMART) involves restoring SDF-treated teeth with tooth-coloured materials, which effectively conceals the dark stains while also addressing structural loss from cavitation, thereby enhancing both aesthetics and masticatory function. [10] Studies have reported favourable outcomes when combining SDF with tooth-coloured restorations, noting increased parental acceptance for this approach in managing childhood caries.[11]

The interaction between heterogeneous materials, including anticaries agents and restorative materials, can occur when utilized for the remineralizion of the affected dentin and restoring lost tooth structure, respectively. Research indicates that the adhesiveness and bond strength of restorative materials are influenced by caries-affected dentin, differing from their adhesion to sound dentin. Additionally, pre-treatment materials applied to dentin before restorative procedures may negatively impact the bonding efficacy of subsequent restorative materials.[1,12] Consequently, this study aimed to assess the microtensile bond strength (µTBS) of restorative materials, specifically flowable resin-based composite (FRC) and glass ionomer (GIC) restoration, when bonded to silver diamine fluoride (SDF)-treated demineralized dentin. The null hypothesis proposed that SDF-treated demineralized dentin would not alter the µTBS values of these restorative materials.

MATERIALS AND METHODS

Sample size calculation

A power analysis was conducted to determine the minimum sample size required to detect significant differences in microtensile bond strength (µTBS) between groups. Based on a study by **Osama et al., (2024)**[13], an effect size (*f*) of 0.538 was used, with an alpha (α) level of 0.05 and a beta (β) level of 0.20 (80% power). The analysis, conducted using G*Power software (v. 3.1.9.7)[14], indicated a total sample size of 30 specimens (15 per group) to ensure adequate statistical power.

Sample Collection and Preparation

Thirty freshly extracted human primary molars with dentin caries were collected from Paediatric Dentistry and Dental Public Health Department, Faculty of Dentistry, Cairo University following inclusion criteria: no pulp exposure, cavity openings with a diameter of 2 mm or greater to permit manual instrumentation access. Extracted primary teeth with developmental defect or previous restoration were excluded. Following teeth extraction due to normal shedding or orthodontic reasons, dental tissue debris and calculus were ultrasonically debrided from the teeth. Teeth were disinfected in a 0.02% thymol solution for one week, stored in room temperature saline for up to one month.[15]

Carious dentin was selectively removed from the lesion by the main investigator utilizing a hand excavator (A Titan, New York, USA). Subsequent assessment of the cavity surface was conducted through tactile examination, wherein the absence of a 'tug-back' sensation upon probing with a blunt-ended explorer was considered indicative of complete debridement. [16] The cavity was washed thoroughly with water, to remove all debris then dried by air.

Randomization was performed by the operator using the www.random.org online platform with thirty teeth allocated equally into two groups (n=15) based on the restorative material: Group I received flowable resin composite restoration while Group II received glass ionomer restoration. The generated random sequences for the containers were kept with the co-supervisor and schematic drawing of the allocation concealment.

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Teeth mounting

To standardize the mounting of the selected teeth, each specimen was vertically positioned within a cylindrical teflon mold, which was then filled with auto polymerized acrylic resin (Acrostone acrylic material, acrostone dental and medical supplies, Egypt). This protocol ensured that the tooth's root was securely embedded in the resin, while the cemento-enamel junction was consistently maintained 2 mm above and parallel to the resin surface.[17]

Restorative procedures of the teeth

A single drop of 38% SDF (Advantage arrest, Care, West Palm Beach, FL, USA) was precisely applied to the surface of each prepared specimen using a micro-brush. The agent was left undisturbed for a period of 3 minutes to allow optimal interaction with the tooth substrate. Subsequently, the specimens were thoroughly rinsed for 30 seconds utilizing an air/water spray and gently air-dried for 5 seconds, following protocols mentioned in previous studies. [18,19]

Flowable resin composite (group I)

35% phosphoric acid etchant (Ultra-etch acid etch, Ultradent, UT, USA) was applied for 15 seconds in accordance with the manufacturer's guidelines. The etching agent was then removed using an air/water syringe for 5 seconds, followed by air-drying.[20] Then, an adhesive resin (Bondfix, Voco, Cuxhaven, Germany) was applied to the dentin surface of each specimen act for 20 seconds then dispersed using an air stream for a minimum of 5 seconds and subsequently polymerized using an LED curing unit (O-light Max Dental curing unit, Woodpecker. Co., LTD, Guangxi, China) for 10 seconds, according to the manufacturer's instructions (Voco dental products Instructions for use. Voco, Germany). Flowable resin composite (Wave mv, SDI, IL, North America) was incrementally placed into the cavity following adhesive application using a carver and ball burnisher to ensure adaptation. Excess material was carefully removed with a carver, and the restoration was light-cured for 40 seconds according to the manufacturer's recommendations. [21] Final polishing and finishing procedures were conducted on all specimens using a low-speed handpiece under light pressure to standardize surface smoothness.

Glass ionomer cement restoration (group II)

A cavity conditioner was applied to each specimen for 10 seconds, followed by rinsing with a water spray for 10 to 20 seconds and gentle air-drying, in accordance with standardized procedures. Subsequently, glass ionomer cement restoration (Fuji II LC, GC corporation, CO Tokyo, Japan) was dispensed directly onto the treated surfaces. The material was prepared by agitating the capsule in an amalgamator for 10 seconds at an approximate speed of ±4000 RPM. The capsule was placed into an applicator and dispensed into the cavity. The material was then adapted with a carver and a ball burnisher. Excess cement was carefully removed, and the material was polymerized using a LED curing unit for 20 seconds, in accordance with the manufacturer's guidelines. [22] All specimens were finished and polished using a low-speed handpiece under light pressure. Finally, a layer of Equia™ Coat (GC corporation, CO Tokyo, Japan) was applied over the restorations and light-cured for 10 seconds following recommended instructions to ensure optimal surface sealing and protection.[22]

Mechanical aging

Following the completion of finishing and polishing procedures, all specimens were stored in distilled water at 37 °C for a period of 24 hours. Thermocycling was then performed using a programmable logic-controlled equipment (Multimodal ROBOTA chewing simulator, Model ACH-09075DC-T, AD-TECH TECHNOLOGY CO., LTD., GERMANY), subjecting the samples to 500-cycle between 5 °C and 55 °C (Pazinatto et al., 2003) based on ISO/TS (E) 11405:2003 [25], with a dwell time of 60 seconds in each bath. [13,26]

Microtensile bond strength testing

The specimens, previously embedded in acrylic resin blocks, were subsequently positioned within an automated precision diamond microsaw (Isomet 4000, Buehler Ltd., Lake Bluff, IL, USA) for all sectioning processes. To standardize the preparation, the occlusal surfaces were systematically planed to the level of the dentinoenamel junction (DEJ) under continuous irrigation using a water-soluble, anticorrosive cooling lubricant (Cool 2, Buehler Ltd., Lake Bluff, IL, USA), prepared at a dilution ratio of 1:33 (lubricant to water) to ensure optimal thermal control during cutting.

To facilitate the preparation of standardized composite-dentin or glass ionomer-dentin specimens, restored teeth were sectioned longitudinally to yield rectangular beams with approximate cross-sectional dimensions of 1 × 1 mm. Each beam incorporated composite resin and dentin or glass ionomer and dentin, with the adhesive interface centrally located between the two substrates.

A custom-fabricated holding fixture was employed to ensure that longitudinal cuts were executed perpendicularly to the flat occlusal plane of each restored tooth. This fixture securely housed the acrylic blocks each containing an embedded tooth in a position parallel to the cutting axis. The fixture was composed of a metallic housing with two tightening screws for stabilization and featured a square base that was soldered to the metal housing to preserve the orthogonal orientation required for bucco-lingual and mesio-distal sectioning at 90° angles. The assembled unit was mounted onto a precision diamond saw for sectioning. Using a 0.3 mm thick diamond-coated cutting blade, serial sections were first made in the bucco-lingual direction under continuous water irrigation to mitigate heat generation. The sample was subsequently rotated 90° to enable sectioning in the mesio-distal direction. A final horizontal cut was performed at the cemento-enamel junction to isolate beams of the desired dimensions. The resulting specimens had a thickness of 1.0 ± 0.1 mm, verified using a digital caliper (Total Tools, Malaysia). Each beam was then immersed in distilled water at ambient temperature and stored in sealed, labeled plastic containers.

Each test beam was secured onto a custom-designed jig using a cyanoacrylate-based adhesive (Akfix 705 Fast Adhesive, Turkey) applied at both extremities of the specimen, maintaining a minimum distance of 1 mm from the adhesive interface to prevent interference with the bonding zone. A polymerization accelerator was employed to facilitate rapid curing of the adhesive. The assembled jig was subsequently positioned within a universal testing machine (Instron, MA, USA) equipped with a 500 N load cell. A uniaxial tensile load was applied at a crosshead speed of 0.5 mm/min until interfacial failure of the adhesive bond occurred.

A single beam was selected from each specimen for testing, and the force (N) required to induce restoration displacement was recorded. The microtensile bond strength (μTBS) was subsequently calculated by dividing the load at failure (N) by the cross-sectional bonding area (1 mm²). The micro-tensile bond strength (μTBS) was computed and expressed in megapascals (MPa) using the accompanying Bluehill Lite software (Instron, MA, USA).[27]

Failure mode Examination

Following fracture, each specimen was subjected to microscopic evaluation using a stereomicroscope at 40× magnification to determine the specific failure pattern. The observed failure patterns were categorized into three distinct types: (1) adhesive failure occurring at the interface between dentin and either the FRC or the GIC restoration; (2) cohesive failure confined within the FRC or the GIC restoration; and (3) mixed failure, characterized by a combination of adhesive and cohesive failures. [28]

Statistical analysis

Statistical analysis was conducted using SPSS® version 27, GraphPad Prism®, and Microsoft Excel® 2016. Normality of data distribution was assessed using the Shapiro-Wilk and Kolmogorov-Smirnov tests, confirming parametric assumptions. Between-group comparisons were analysed using independent samples t-tests for quantitative data. Qualitative data were expressed as frequencies and percentages, with intergroup comparisons performed using Fisher's exact test. The significance threshold was set at $p \leq 0.05$ for all statistical tests.

RESULTS

I. Microtensile strength

Group I (FRC) recorded a mean tensile strength of 13.25 ± 2.30, while Group II (GIC restoration exhibited a significantly lower mean value of 5.72 ± 0.26. The difference between the means was 7.532 ± 0.5971, with a 95% confidence interval ranging from 8.755 to 6.309. The independent t-test indicated that this difference was statistically significant (P < 0.0001), confirming that the tensile strength of Group I was significantly higher than that of Group II **(Table 1 and Figure 1).**

Table 1. Tensile strength of Group I and Group II, comparison between groups using independent t test.

GROUPS	M	SD	DIFFERENCE BETWEEN MEANS ± SEM	95% CONFIDENCE INTERVAL	P VALUE
Group I (Flowable Resin Composite)	13.25	2.30	-7.532 ± 0.5971	-8.755 to -6.309	<0.0001*
Group II (Glass Ionomer)	5.72	0.26			

**Significant difference as P≤ 0.05.*

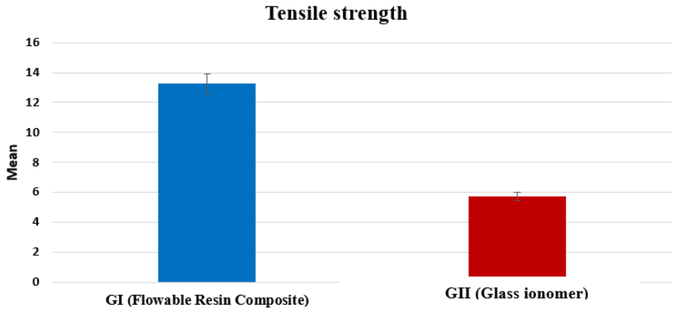

Figure 1. Bar chart showing Tensile strength of GI and GII.

II. Failure mode

Comparison between the two groups regarding the mode of failure was performed by using Fisher's Exact test which revealed a statistically significant difference (P = 0.01). In Group I, all specimens (100%) exhibited a mixed failure mode, with no adhesive or cohesive failures recorded. In contrast, Group II showed a more varied failure pattern, with 53.3% mixed failures, 20.0% adhesive failures, and 26.7% cohesive failures. The distribution difference between the two groups was statistically significant, indicating that Group I predominantly experienced mixed failures, while Group II demonstrated a combination of mixed, adhesive, and cohesive failures **(Table 2 and Figure 2).**

Table 2. Comparison between groups regarding failure modes.

	GROUP				
	GI (Flowable Resin Composite)		**GII (Glass Ionomer)**		**P VALUE**
	Count	Column N %	Count	Column N %	
Mixed	15	100.0%	8	53.3%	0.01*
Adhesive	0	0.0%	3	20.0%	
Cohesive	0	0.0%	4	26.7%	

**Significant difference as P ≤ 0.05.*

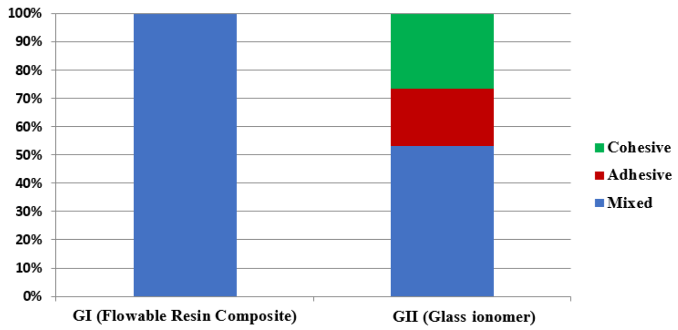

Figure 2. Stacked bar chart represents distribution of different failure modes among groups.

DISCUSSION

Silver diamine fluoride (SDF) has emerged as widely used option and presents an alternative approach for caries prevention, particularly in preschool-aged children due to its minimal risk, high efficacy, affordability, and practical applicability.[27,29] Despite its growing adoption, questions have been raised regarding its potential effects on the adhesion of restorative materials to dentin.[10]

Literature indicated that SDF exhibits notable antimicrobial properties against cariogenic biofilm.[30,31] Additionally, it demonstrated rehardening effects on tooth structure. The mechanism of for this rehardening is believed to occur through the reaction between SDF and hydroxyapatite, producing fluoroapatite and insoluble silver phosphate.[9,32] The release of fluoride ions and subsequent deposition of silver phosphate contributed to tooth remineralization and structural rehardening. [33] Studies have reported elevated mineral content in caries-affected dentin following SDF application compared to sound dentin.[34,35]

A critical factor for the success of dental restoration is the quality of the bond formed between the restorative material and the tooth structure. The presence of any material on the dentin or enamel surfaces prior to a procedure can compromise this adhesion, ultimately leading to a reduction in the restoration's mechanical performance.[36]

The effectiveness of a restoration in preventing recurrent caries is determined by evaluating two key properties: the bond strength to the tooth structure and its ability to create a tight seal at the cavity margins. Assessing these factors is important to determine its clinical performance.[13]

The effect of SDF as a pretreatment on the bond strength of restorative materials had been a subject of interest in the literature. However, a notable gap remained in the research. Studies specifically comparing the microtensile bond strength of FRC and GIC restoration after SDF application were still rare. Therefore, the aim of the present study was to directly address this gap by evaluating the effect of SDF on the microtensile bond strength of FRC and GIC restoration to carious-affected primary dentin.

The null hypothesis that there was no statistically significant difference in microtensile bond strength between the FRC and GIC restoration groups was rejected. The present study found a significantly superior microtensile bond strength for FRC group (13.25 ± 2.30) compared to GIC restoration group (5.72 ± 0.26) after dentin pretreatment with 38% SDF. The improved bond strength with composite resin could be attributed to several factors. The action of phosphoric acid, which was believed to remove the black precipitate formed by the SDF treatment, thereby enhancing the biomechanical adhesion of the restorative material.[37] Furthermore, SDF's alkalinity promoted phosphorylation, which gave dentin a negative charge that attracts calcium ions and encourages new hydroxyapatite crystal formation. This created nucleation sites, increasing the mineral content. The newly formed hydroxyapatite allowed 10-MDP monomers from dental adhesives to adsorb, forming MDP-calcium salts that integrates with collagen fibrils. This process enhanced the bond strength.[2] This observation might also be attributed to the distinct adhesion mechanisms of each restorative material. Retention for the flowable composite was achieved through adhesive systems that create a micromechanical bond after phosphoric acid etching, whereas the GIC restoration relies primarily on chemical adhesion.[38]

This finding aligns with the general observation by Haradwala et al. (2022)[28] that composite resin demonstrated higher bond strength than glass ionomer, although their study did not find this difference to be statistically significant. Similarly, Aldosari and Al-Sehaibany, (2022)[1] reported similar findings, with resin composite showing the highest µTBS, followed by RMGI, while GIC exhibited the lowest µTBS. The observed superiority in µTBS of the FRC over the GIC restoration was further supported by Ahangari et al. (2020)[39] who demonstrated that a nano-hybrid composite resin (Filtek Z350 XT) achieved a significantly higher bond strength than RMGI, a difference they attributed to the formation of a resin-infiltrated hybrid layer in intertubular dentin, which creates a superior micromechanical bond.

Analysis of the failure patterns identified the weakest region within the adhesive-dentin interface.[17] The FRC group exhibited a 100% mixed failure mode. The mixed failure mode observed in this study suggests a favorable adhesive bond strength.

This finding is consistent with studies by Haradwala et al., (2022)[28] and Hafijullah et al., (2025)[40], which also reported a high prevalence of mixed failures in composite restorations. The observed mixed pattern of failure suggests that the adhesive interface possessed considerable strength. Consequently, fracture occurred within the weaker cohesive structures of the surrounding dentin and the restorative material itself, rather than solely at the bond interface. While this indicates a durable initial bond, a high rate of mixed failure can complicate clinical repair and may suggest potential weakness under long-term cyclic loading.

This finding contrasts with the study by Ko et al. (2020)[41], who reported that the application of SDF solution on dentin prior to composite resin restoration primarily resulted in adhesive failure. They suggested that this outcome could be due to a potential adverse effect of high fluoride concentrations on the dentin bonding mechanism.

The present study showed a more varied failure pattern with a predominant mixed failure in the GIC restoration group. The predominant mixed failure mode suggested a high retentive strength between GIC restoration and SDF-treated primary dentin. This is likely due to the formation of silver phosphate (Ag_3PO_4) and calcium fluoride (CaF_2) from the reaction between SDF and calcium hydroxyapatite. The silver phosphate may then interact with the carboxylic groups in the GIC, enhancing the bond to the dentin.[42]

This finding is similar to a study by Soliman et al., (2021)[42], Banerjee et al., (2024)[43] and Das et al., (2024) [44] who found that RMGI used after SDF pretreatment also resulted in mostly mixed failures. This finding may be attributed to the role of silver phosphate in aiding remineralization, thereby promoting the rehardening of softened tooth structure. On the contrary, a comparable study by Chu et al., (2012)[45] on the microtensile bond strength of GIC to sound primary dentin reported that cohesive failures within the GIC were the most frequent, accounting for 39% of the failures. This discrepancy might be attributed to the altered mechanical properties of the dentin treated with SDF, as well as the presence of residual carious dentin. These factors could lead to a more elastic bonding interface compared to that of unaffected dentin.

The varied failure pattern observed in the GIC restoration group indicates a less predictable clinical outcome, as bonding and material properties variably influence its performance. The presence of mixed failure may be associated with comparatively increased adhesive strength. Cohesive failure can result from various factors, including improper specimen alignment during testing, microcracks induced during specimen preparation, or the material's inherent brittleness. Adhesive failure indicated a weak bond between the dentin and the material.

This study has several limitations that should be considered when interpreting the results. This study used primary teeth as the bonding substrate because our research was relevant to pediatric dentistry. However, this may limit the generalizability of our findings to permanent teeth. Caries excavation was performed utilizing a hand instrument (spoon excavator), which in clinical scenarios may not be entirely adequate and could potentially require supplementary rotary instruments to refine margins and eliminate unsupported enamel.

Clinical trials are recommended to evaluate the long-term performance, durability, and clinical success rates of both restorative materials on SDF-treated primary dentin. Also, future studies should be expanded to include additional restorative materials, such as newer bioactive materials.

CONCLUSION

Within limitation of this study, this study concluded that:

- Regarding the microtensile bond strength, the flowable resin composite demonstrated significantly higher bond strengths to SDF-treated dentin compared to the GIC restoration.
- The predominate failure mode of flowable resin composite was mixed indicating a high bond strength between the restoration and the SDF-pretreated dentin. The observed failure mode distribution for the GIC restoration was significantly more varied compared to the other group. This lack of heterogenicity indicated that the bonding interface between GIC restoration and SDF-pretreated dentin is less reliable and has lower predictability.

DECLARATION

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Competing and conflicting Interests
The authors report there are no competing interests to declare.

Ethical approval
The study protocol was reviewed and approved by the Research Ethics Committees (REC) of the Faculty of Dentistry, Cairo University, Egypt on 28/5/2024 with approval number 26524.

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