

Bond Strength of Three Ion-Releasing Restorative Materials to Primary Dentin Following Silver Fluoride Pretreatment: An In Vitro Study

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Research Article

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Abstract

Background

This study evaluated the shear bond strength of fluoride-releasing restorative materials to primary dentin under different conditions, including silver fluoride pretreatment and aging.

Methods

Dentin specimens obtained from 180 extracted primary molars were categorized as sound or artificially demineralized. Three restorative materials—high-viscosity glass ionomer cement (Fuji IX), resin-modified glass ionomer cement (Fuji II LC), and an alkasite material (Cention Forte)—were applied to sound dentin, demineralized dentin, and demineralized dentin treated with SF. Half of the specimens were subjected to 500 thermal cycles. Shear bond strength was measured, fracture types were assessed stereomicroscopically, and two specimens from each group was examined using scanning electron microscopy.

Results

Cention Forte demonstrated significantly higher bond strength than Fuji IX and Fuji II LC on sound and demineralized dentin ($p < 0.05$). No significant differences were observed among materials on SF-treated dentin ($p > 0.05$). Aging had a limited overall effect; however, significant differences between thermocycled and non-thermocycled specimens were observed only for Fuji II LC and Cention Forte in the SF-treated groups ($p < 0.05$). Adhesive and mixed failures predominated, with no significant differences among groups ($p > 0.05$).

Conclusion

The bond performance of fluoride-releasing restorative materials was influenced by dentin substrate and SF pretreatment. Cention Forte exhibited superior bond strength under most conditions, although SF application reduced its performance. Aging effects were minimal except on SF-treated dentin.

INTRODUCTION

Dental caries is a chronic, multifactorial disease of the primary dentition that can cause pain, functional impairment, and negatively impact children's growth and development[1]. Traditionally, caries was managed through conventional restorative techniques [2], which often require extensive cavity preparation, thereby increasing the risk of pulp exposure and unnecessary loss of tooth structure [3]. The invasive nature of these procedures can prolong treatment time and complicate management, and in patients with special health care needs or cooperation challenges, may necessitate sedation or general

anesthesia, thereby increasing systemic risks and healthcare costs [4]. Therefore, minimally invasive dentistry has emerged as a conservative and patient-friendly alternative for caries management in pediatric patients. The fundamental principle of these approaches is the integration of preventive strategies with conservative operative interventions [5]. Among the minimally invasive techniques used for cavitated primary teeth are partial caries removal, the Hall Technique, Atraumatic Restorative Treatment (ART), and Silver-Modified Atraumatic Restorative Treatment (SMART), all of which have demonstrated favorable clinical outcomes [6] .

As one of the minimally invasive approaches, Atraumatic Restorative Treatment (ART) involves removing carious tissue using only hand instruments and restoring the cavity with a fluoride-releasing material [7]. Initially indicated for disadvantaged communities with limited access to dental care, ART has since demonstrated favorable clinical performance and is now recognized as a minimally invasive option suitable for the general population, particularly for uncooperative pediatric patients and individuals with special health care needs. Several studies have reported that ART provides clinical outcomes comparable to conventional restorations [8]. Building on the principles and clinical success of ART, further developments have aimed to enhance its therapeutic potential and expand its applicability. The Silver-Modified Atraumatic Restorative Treatment (SMART) approach was introduced to combine the antibacterial and remineralizing effects of silver diamine fluoride (SDF) with the restorative and fluoride-releasing properties of the restorative material, thereby supporting caries arrest while preserving pulp vitality [9].

In the success of minimally invasive treatment approaches, not only the selected clinical technique but also the choice of restorative material plays a critical role. Restorative materials used in minimally invasive approaches such as ART and SMART should allow for simple and time-efficient application, provide adequate durability, inhibit dentinal collagen-degrading enzymatic activity [10], and ensure sustained ion release [11].

Based on these considerations, the present study aims to compare the bond strength of three distinct restorative materials utilized within the ART and SMART protocols. Specifically, it evaluates their adhesion to sound dentin, artificially demineralized dentin, and artificially demineralized dentin treated with silver fluoride (SF), an ammonia-free formulation of silver diamine fluoride (SDF), under both thermocycled and non-thermocycled conditions.

MATERIALS AND METHODS

Following approval by the Clinical Research Ethics Committee of Akdeniz University (25.07.2024/TBAEK-502).Teeth were collected from patients at the Department of Pediatric Dentistry, Faculty of Dentistry, Akdeniz University, primary second molars extracted either for orthodontic reasons or due to physiological root resorption were collected after obtaining prior parental consent. The inclusion criteria were primary second molars without caries or with enamel-limited lesions, with no developmental defects, and with at least one-third of the root structure remaining intact. Teeth with restorations, cracks,

or fractures were excluded. Maxillary and mandibular teeth were equally distributed among the study groups. 180 primary second molars were randomly allocated into 18 groups ($n = 10$ per group).

After removal of periodontal tissue remnants, the teeth were stored in 0.1% thymol solution for up to 6 months. The pulp chambers were filled with composite material (DenFil™, Vericom, South Korea), and the teeth were embedded in cold-cure acrylic resin (IMICRYL®, Turkey) using prefabricated L-shaped silicone molds. Buccal or lingual enamel surfaces were removed with a low-speed diamond saw (ISOMET™ 1000, Buehler, USA) to expose suitable dentin areas for restoration. Teeth with dentin surface area to accommodate a 4 mm internal diameter mold were excluded. The selected surfaces of 180 teeth were polished for 15 seconds using 800- and 1200-grit silicon carbide papers. Samples were randomly numbered and divided into three main material groups ($n = 60$) [FIX; Fuji IX (Fuji IX GP EXTRA, GC Corporation, Tokyo, Japan), FII; Fuji II LC (GC Corporation, Tokyo, Japan), and CF; Cention Forte (Ivoclar Vivadent AG, Schaan, Liechtenstein)], each further subdivided according to dentin surface condition [sound dentin as control surface ($n = 20$), artificially carious dentin ($n = 20$) and artificially carious + SF ($n = 20$)]. Each subgroup was then divided into two, based on whether thermal cycling was applied ($n = 10$) (Fig. 1).

Study Protocol

Artificial carious lesions were induced in 40 specimens from each material group using a pH-cycling protocol. All specimen surfaces, except those designated for caries induction, were coated with two layers of acid-resistant varnish prior to the artificial caries procedure. The demineralizing solution consisted of 2.2 mM calcium chloride (CaCl_2), 2.2 mM sodium dihydrogen phosphate (NaH_2PO_4), and 50 mM acetic acid, adjusted to pH 4.8. The remineralizing solution contained 1.5 mM calcium chloride (CaCl_2), 0.9 mM sodium dihydrogen phosphate (NaH_2PO_4), and 0.15 M potassium chloride (KCl), adjusted to pH 7.0. Each set of specimens was immersed in the demineralizing solution for 8 hours, followed by 16 hours in the remineralizing solution, and this cycle was repeated daily for 14 days at room temperature [12].

For artificially carious + SF surfaces, a silver fluoride (SF) solution (Riva Star Aqua, SDI Limited, Bayswater, Victoria, Australia) was applied to 20 specimens from each material group with artificially demineralized dentin. Before application, the surfaces were rinsed with distilled water and gently air-dried. SF solution was applied to the dentin surface with a microbrush for one minute, in accordance with the manufacturer's instructions, followed by gentle air-drying.

Before restoration, all dentin surfaces were cleaned with a cotton pellet, and prefabricated circular molds (4 mm internal diameter) were positioned on the surfaces. All capsule-based restorative materials (FIX, FII, and CF) were mixed using a mixer (Ultramat 2, SDI Limited, Bayswater, Victoria, Australia), applied into the molds with an applicator, applied a single increment and the molds were removed after initial setting. The FIX material was mixed for 10 seconds, condensed for 2 minutes. The FII material was mixed for 10 seconds, and light-cured for 20 seconds using an light-emitting diode (LED) curing unit

(Woodpecker® LED Light Curing Unit, Guilin, China). For the CF material, the dentin surface was pretreated with the manufacturer's primer for at least 10 seconds and gently air-dried to form a thin glossy layer; the capsule was then mixed for 15 ± 2 seconds, condensed for 2 minutes, and light-cured for 20 seconds.

Following the restorative treatments, all the specimens were kept in distilled water for 48 hours before they were divided into thermocycled and non-thermocycled groups. Those specimens intended for thermocycling were kept in a thermocycling unit (Mod Dental, Esetron, Turkey) and cycled 500 times between deionizing water baths at $55 \pm 5^\circ\text{C}$ and $5 \pm 5^\circ\text{C}$. Each bath had the dwell time of 30 seconds, 10 second transfer time for 500 cycles [13]. Both non-thermocycled and thermocycled specimens were placed in plastic mold for shear bond strength tests and mounted on the universal test machine (MOD Dental MIC-101, Esetron SMART Robotechnologies Ankara, Türkiye). Parallel shear load was applied at 1 mm/min crosshead speed until the moment of the failure. For each specimen, the fracture load was measured and the bond strength was determined in megapascals (MPa). All the specimens were examined using a stereomicroscope (Zeiss Stemi 508, Carl Zeiss Microscopy GmbH, Germany), and the types of fractures were identified as adhesive, cohesive, or mixed. Additionally, two specimens from each group were selected for SEM analysis; after drying and Au–Pd coating, the samples were examined and using scanning electron microscope (Leo 1430 VP, Carl Zeiss, Germany) at $\times 500$, $\times 1000$ and $\times 2500$ magnifications. The flowchart of the study is presented in Fig. 2.

The Statistical Package for the Social Sciences (SPSS) (v.22.0, IBM, Chicago, IL, USA) was used for the statistical analysis. The mean and standard deviation values of the shear bond strength for all tested groups were compared using analysis of variance (ANOVA) with Tukey's post hoc test. The differences in the non-thermocycled and thermocycled shear bond strength of each material were evaluated with an independent t-test. Fisher's exact test was conducted to analyze the pattern of different fracture types.

RESULTS

A total of 180 specimens that met the inclusion criteria were included in the study, with 10 specimens in each group. During thermocycling, some restorations failed and these specimens were excluded from the analysis. The excluded specimens were three from the sound dentin–FIX group, one from the demineralized dentin–FIX group, two from the demineralized dentin–FII group, four from the SF-treated demineralized dentin–FII group, and three from the SF-treated demineralized dentin–CF group.

In the non-thermocycled groups, the highest mean shear bond strength was observed on both sound and artificially carious dentin in the CF group, followed by FIX and FII. On these dentin surfaces, CF exhibited significantly higher bond strength than FIX and FII ($p < 0.05$), while no significant difference was observed between FIX and FII ($p = 0.999$). On the artificially demineralized dentin + SF surfaces, CF exhibited the highest mean bond strength, followed by FII and FIX; nonetheless, the differences among the groups were not statistically significant ($p = 0.269$). When shear bond strength was compared according to the restorative materials applied on different dentin surfaces, in the case of FIX, the highest

values were obtained from restorations on artificially carious dentin, followed by sound and artificially demineralized dentin + SF surfaces ($p > 0.05$). Regarding FII, the highest mean bond strength was recorded on artificially demineralized dentin + SF surfaces, followed by artificially carious and sound dentin surfaces ($p > 0.05$). As for CF, the highest values were obtained from restorations on sound dentin, followed by artificially carious and artificially demineralized dentin + SF surfaces. Although no significant difference was found between sound and artificially carious dentin ($p = 0.884$), a statistically significant difference was observed between artificially demineralized dentin + SF surfaces and other surfaces ($p < 0.05$). The mean shear bond strength values of the non-thermocycled specimens are presented in Table 1 and Fig. 3.

Table 1

Mean shear bond strength values obtained from the restorative material groups applied to different dentin surfaces without thermal cycling.

Material	Sound Dentin Mean $\pm$ SD (MPa)	Artificially Carious Dentin	Artificially Carious Dentin + SF Solution
		Mean $\pm$ SD (MPa)	Mean $\pm$ SD (MPa)
Fuji IX	5,28 $\pm$ 2,47 ^a	5,32 $\pm$ 3,02 ^c	4,32 $\pm$ 2,26
Fuji II LC	4,95 $\pm$ 2,95 ^b	5,25 $\pm$ 3,02 ^d	6,02 $\pm$ 3,69
Cention Forte	16,37 $\pm$ 7,49 ^{abx}	14,73 $\pm$ 7 ^{cdy}	6,75 $\pm$ 4,03 ^{xy}
* Significant differences between materials on the same dentin surface and significant differences ($p < 0.05$)			

In the groups subjected to thermal cycling, the shear bond strength values obtained from restorations on sound and artificially carious dentin surfaces demonstrated that CF achieved significantly higher values than FII and FIX ($p < 0.05$). Whereas no significant difference was detected between FIX and FII ($p > 0.05$). For restorations placed on artificially demineralized dentin treated with SF, the highest bond strength values were observed in the FIX group, followed by CF and FII, with no significant differences among the groups ($p > 0.05$).

When shear bond strength was compared according to the restorative materials applied on different dentin surfaces in the thermocycled specimens, with respect to FIX, the highest mean value was obtained from sound dentin, followed by artificially demineralized and artificially demineralized dentin + SF surfaces ($p > 0.05$). In relation to FII, the highest bond strength was found on sound dentin, followed by artificially demineralized and artificially demineralized dentin + SF surfaces. There were no significant differences between sound and demineralized dentin ($p = 0.998$) or between demineralized and SF-treated demineralized dentin ($p = 0.354$); however, restorations on sound dentin exhibited significantly higher bond strength than those on SF-treated dentin ($p = 0.04$). In terms of CF, the highest mean bond strength was recorded on artificially demineralized dentin, followed by sound and artificially demineralized dentin + SF surfaces. No significant difference was observed between sound and

demineralized dentin ($p = 0.995$), whereas statistically significant differences were found between demineralized and SF-treated dentin ($p < 0.001$) and between sound and artificially demineralized dentin + SF surfaces ($p = 0.003$).

Upon evaluating the effect of thermocycling on sound dentin, higher bond strength values were recorded in the thermocycled FIX and FII groups, whereas a lower value was observed in the thermocycled CF group; however, these differences were not statistically significant ($p > 0.05$). In artificially demineralized dentin, bond strength values were lower in the thermocycled FIX and CF groups and higher in the thermocycled FII group, with no statistically significant differences between thermocycled and non-thermocycled groups ($p > 0.05$). In artificially demineralized dentin treated with SF solution, higher bond strength was observed in the thermocycled FIX group, whereas higher values were recorded in the non-thermocycled FII and CF groups. The difference between thermocycled and non-thermocycled groups was statistically significant for FII ($p = 0.007$) and CF ($p = 0.003$), while no significant difference was observed for FIX ($p = 0.654$). The mean shear bond strength values of the thermocycled specimens are presented in Table 2 and Fig. 3.

Table 2

Mean shear bond strength values obtained from the restorative material groups applied to different dentin surfaces with thermal cycling.

Material	Sound Dentin Mean $\pm$ SD (MPa)	Artificially Carious Dentin	Artificially Carious Dentin + SF Solution
		Mean $\pm$ SD (MPa)	Mean $\pm$ SD (MPa)
Fuji IX	5,91 $\pm$ 3,18	4,72 $\pm$ 1,79	4,82 $\pm$ 2,62
Fuji II LC	6,19 $\pm$ 3,26	5,78 $\pm$ 4,61	2,87 $\pm$ 1,41
Cention Forte	13,42 $\pm$ 7,44 ^x	13,78 $\pm$ 4,82 ^y	3,63 $\pm$ 1,83 ^{xy}
* Significant differences between materials on the same dentin surface and significant differences ($p < 0.05$)			

Following a thorough evaluation of the fracture types, it was observed that mixed and adhesive failures were predominant across all groups, whereas cohesive failures occurred with relatively limited frequency. The distribution of these fracture types, after the application of restorative materials on various dentin surfaces—both with and without thermocycling procedure—is detailed in Figs. 4 and 5. SEM images of the different groups are presented in Fig. 6.

DISCUSSION

Dental caries, one of the most common childhood diseases, affects not only oral health but also overall growth and quality of life. Conventional methods are routinely used; however, they can be challenging for children with limited cooperation or medical and behavioral conditions. Studies have shown that 29.33% of patients aged 6–12 experience dental anxiety and 28.67% exhibit behavioral problems during

conventional treatment [14], while in patients with Autism Spectrum Disorder, 68% display anxiety and poor cooperation [15]. The limited acceptance of conventional approaches has shifted attention toward minimally invasive techniques [16]. In this context, the present study evaluated the ART and SMART techniques—minimally invasive approaches that offer higher acceptance among children with special needs or cooperation difficulties.

When examining studies on the bond strength of glass ionomer-based restorative materials applied to sound dentin, Calvo et al. [17] reported that high-viscosity glass ionomer (HVGIC) exhibited the lowest microtensile bond strength, followed by resin-modified glass ionomer (RMGIC) and nano-filled RMGIC in primary molars, whereas another study found lower shear bond strength for RMGIC compared with HVGIC [18]. Similarly, when evaluating Cention N in comparison with glass ionomer materials on sound dentin, Sulimany et al. [19] reported that Cention N yielded the highest shear bond strength, followed by RMGIC and conventional GIC, and both Cention N and RMGIC showed significantly higher values than conventional GIC. In the present study, although not statistically significant, HVGIC also demonstrated higher bond strength than RMGIC, which may be related to variations in material composition and differences in testing methodologies used across studies. Consistent with these findings and previous reports, Cention N has been shown to exhibit superior bond strength compared with RMGIC or HVGIC [20, 21].

Most studies have reported higher bond strength in sound dentin than in artificially demineralized dentin [17, 22, 23], attributed to the intact mineral structure providing a more stable substrate, whereas demineralization alters collagen and reduces adhesion [24]. Similarly, in our study, CF showed higher bond strength on sound dentin, while RMGIC and HVGIC yielded slightly higher, but not significant, values on caries-affected dentin, consistent with previous findings [17, 25].

In a study comparing the bond strength of different materials to caries-affected dentin, RMGIC, HVGIC, and nano-filled GIC were applied to extracted second primary molars. Microtensile bond strength values were, from highest to lowest, nano-filled RMGIC, RMGIC, and HVGIC, with statistically significant differences among groups [17]. Although evidence on CF is limited, one in vitro study reported that, on artificially demineralized dentin of permanent molars, the shear bond strength values were highest for CF and lowest for HVGIC, with significant intergroup differences [23]. Consistent with previous findings, the present study demonstrated that CF exhibited significantly higher bond strength to artificially demineralized dentin compared with HVGIC and RMGIC.

Various studies have investigated the effects of SDF solutions on the bond strength to demineralized dentin surfaces, yielding inconsistent results. Some authors have suggested that SDF may adversely influence the adhesion of restorative materials to caries-affected dentin. In an in vitro study on permanent molars, FIX restorations placed after SDF application exhibited lower shear bond strength than those on untreated demineralized dentin, although the difference was not statistically significant [26]. The reduction in bond strength following SDF pretreatment has been attributed to silver precipitates obstructing resin infiltration and impairing hybrid layer integrity, as well as to irregular deposits creating

interfacial gaps that hinder adhesion[27]. Conversely, other studies have reported a statistically non-significant increase in the bond strength of HVGIC and RMGIC materials following SDF application [26, 28]. In the present study, the shear bond strength of FIX to SF-treated dentin was lower than that of untreated demineralized dentin, without statistical significance. In contrast, FII applied to artificially demineralized dentin treated with SF demonstrated higher bond strength than the untreated demineralized dentin group, though the difference was not significant. Evidence regarding the interaction between Centon and SDF remains limited. Bassiouny et al.[29] reported that SDF pretreatment did not significantly affect the bond strength of CF. In their study, SDF was applied to sound dentin surfaces, whereas in the present study, it was applied to artificially demineralized dentin. Our findings revealed that SF pretreatment significantly reduced the bond strength of CF on caries-affected dentin.

When the bond strengths of different materials on SF-treated dentin surfaces were compared in the present study, FII had higher bond strength than FIX, though the difference was not significant. Conversely, an in vitro study on artificially carious dentin of permanent molars found higher micro-shear bond strength for HVGIC than for RMGIC after SDF application [30]. This discrepancy may relate to the use of primary teeth in the present study, as their dentin has lower mineralization and distinct tubule morphology that can influence bonding behavior. Upon review of the literature, no studies were found comparing the bond strength of Centon with other restorative materials following SDF application.

The clinical success of restorative materials in pediatric dentistry is closely linked to their dentin bond strength, commonly assessed through artificial aging methods to estimate long-term stability and guide material selection [31]. In an in vitro study conducted on sound dentin surfaces of primary teeth, FII showed the highest shear bond strength after 500 thermal cycles, followed by FIX and FII, with significant differences among the materials[32]. Another study reported that Centon N demonstrated significantly higher bond strength than FII[19], and a study reported that CF showed superior performance compared with Equia Forte and Surefil One after six months of artificial aging [23]. Similarly, in the present study, CF exhibited significantly higher bond strength than FII, while RMGIC showed slightly higher, but not significant, values compared with HVGIC.

Studies on artificially carious dentin subjected to artificial aging have indicated that RMGIC generally exhibits higher bond strength than HVGIC [33, 34]. Additionally, in a study in which Centon N was also evaluated, the highest microtensile bond strength after pH-cycling and thermocycling procedures was reported for Centon N, followed by FII and Equia Forte [35]. Parallel to these findings, the results of the present study were in accordance with the reported outcomes.

Following the aging process, some studies reported a slight, non-significant increase in GIC bond strength after SDF or SDF + KI application [36], whereas others observed a significant reduction, particularly for Centon N and Equia Forte. Within that study, CF showed the highest bond strength, followed by FII and Equia[35]. In the present study, the highest shear bond strength on thermocycled artificially carious dentin treated with SF solution was observed in the FIX group, followed by CF and FII, with no statistically significant differences among them. SF application significantly affected only CF and

FII, while FIX remained unaffected. The discrepancies between studies are likely due to variations in material type and presentation (capsule vs. powder–liquid form).

Studies investigating the effect of aging on the bond strength of comparing RMGIC, HVGIC, and CF are limited in the literature. In the study conducted by Sulimany et al., RMGIC, Cention N, and conventional GIC applied to sound dentin surfaces showed a decrease in bond strength after aging; however, the difference was not statistically significant[19]. In the study conducted by Christoff et al.[23], higher bond strength was observed in the Surefil One and HVGIC groups after aging on sound dentin, whereas no significant change was detected in the CF group. In the same study, all three materials exhibited higher bond strength in their aged groups with artificially carious dentin.

In the present study, unlike the findings of Sulimany et al., RMGIC and HVGIC exhibited higher bond strength in aged groups on sound dentin. Consistent with Christoff et al.[23], both materials showed a non-significant increase, while CF demonstrated no significant change. On artificially carious dentin, similar to Christoff et al., FIX showed higher bond strength after aging, whereas CF and FII displayed a significant decrease, differing from the results of that study. These findings are consistent with previous studies reporting that the post-aging increase in bond strength of glass ionomer cements may be attributed to the completion of acid–base reactions during material maturation and the continuous release of fluoride and other ions, which enhance the chemical bonding with hydroxyapatite and improve interfacial stability[37–40].

This study has certain limitations. Although the samples were randomly assigned, variations in dentin characteristics and depth could not be fully standardized, which may have influenced the uniformity of the restorative surfaces. Moreover, the thermal cycling protocol involved a limited number of cycles, providing only a partial simulation of long-term aging. Blinding of the operator was also not feasible due to visible color differences among the tested materials.

CONCLUSION

It was concluded that FIX, FII, and CF exhibited variable performance depending on the dentin substrate. CF showed the highest bond strength on sound and artificially carious dentin, while FIX and FII presented lower yet clinically acceptable values. Although SF pretreatment reduced the bond strength of CF, it still demonstrated the highest overall performance. Aging had minimal influence on sound and carious dentin, whereas in SF-treated dentin, a non-significant increase was observed for FIX and a significant decrease for CF and FII. These findings may aid clinicians in selecting suitable restorative materials for sound dentin, carious dentin (ART), and SF-treated dentin (SMART) surfaces.

Abbreviations

ART

Atraumatic restorative treatment

ANOVA

Analysis of variance
Au–Pd
Gold–palladium
CF
Cention Forte
FII
Fuji II LC
FIX
Fuji IX
GIC
Glass ionomer cement
HVGIC
High-viscosity glass ionomer cement
LED
Light-emitting diode
MPa
Megapascal
RMGIC
Resin-modified glass ionomer cement
SBS
Shear bond strength
SD
Standard deviation
SDF
Silver diamine fluoride
SEM
Scanning electron microscopy
SF
Silver fluoride
SMART
Silver-Modified Atraumatic Restorative Treatment
SPSS
Statistical Package For The Social Sciences

Declarations

Ethics approval and consent to participate

This study was approved by the Ethical Committee for Clinical Research of Akdeniz University (approval no: TBAEK-502, date: 25.07.2024). Written informed consent was obtained from the parents or legal guardians of all participants prior to the collection and use of the extracted teeth. All procedures were

carried out in accordance with the relevant guidelines and regulations, including the principles of the Declaration of Helsinki.

Consent for publication

Not applicable.

Competing interests

Authors have no conflict of interest to declare.

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Author Contribution

ZKT contributed to conception and design, acquisition, and interpretation of the data and critically revised manuscript. ZZC contributed to conception and design, analysis, and interpretation of the data and critically revised manuscript. NCT contributed to conception and design, analysis, and interpretation of the data and revised manuscript.

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Not applicable.

Data Availability

The data supporting this study's findings are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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Figures

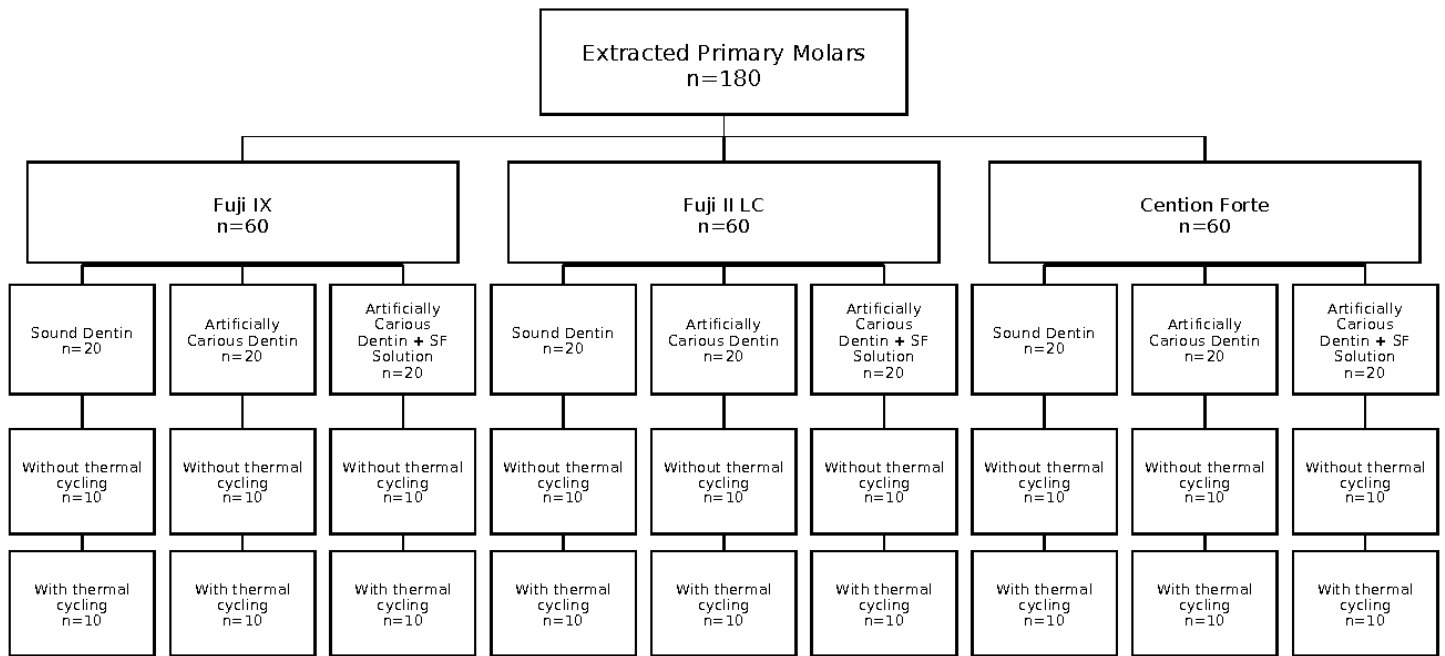


Figure 1

Study design. **Legend:** A total of 180 specimens were randomly numbered, with primary first and second molars evenly distributed across all groups. Specimens were first categorized into three main groups based on the restorative material used. Each main group was then subdivided according to dentin surface condition into sound dentin (control), artificially induced carious dentin without pretreatment (ART), and artificially induced carious dentin treated with a silver fluoride solution (SMART). Finally, all groups were further divided into subgroups depending on whether thermocycling was performed prior to shear bond strength testing.

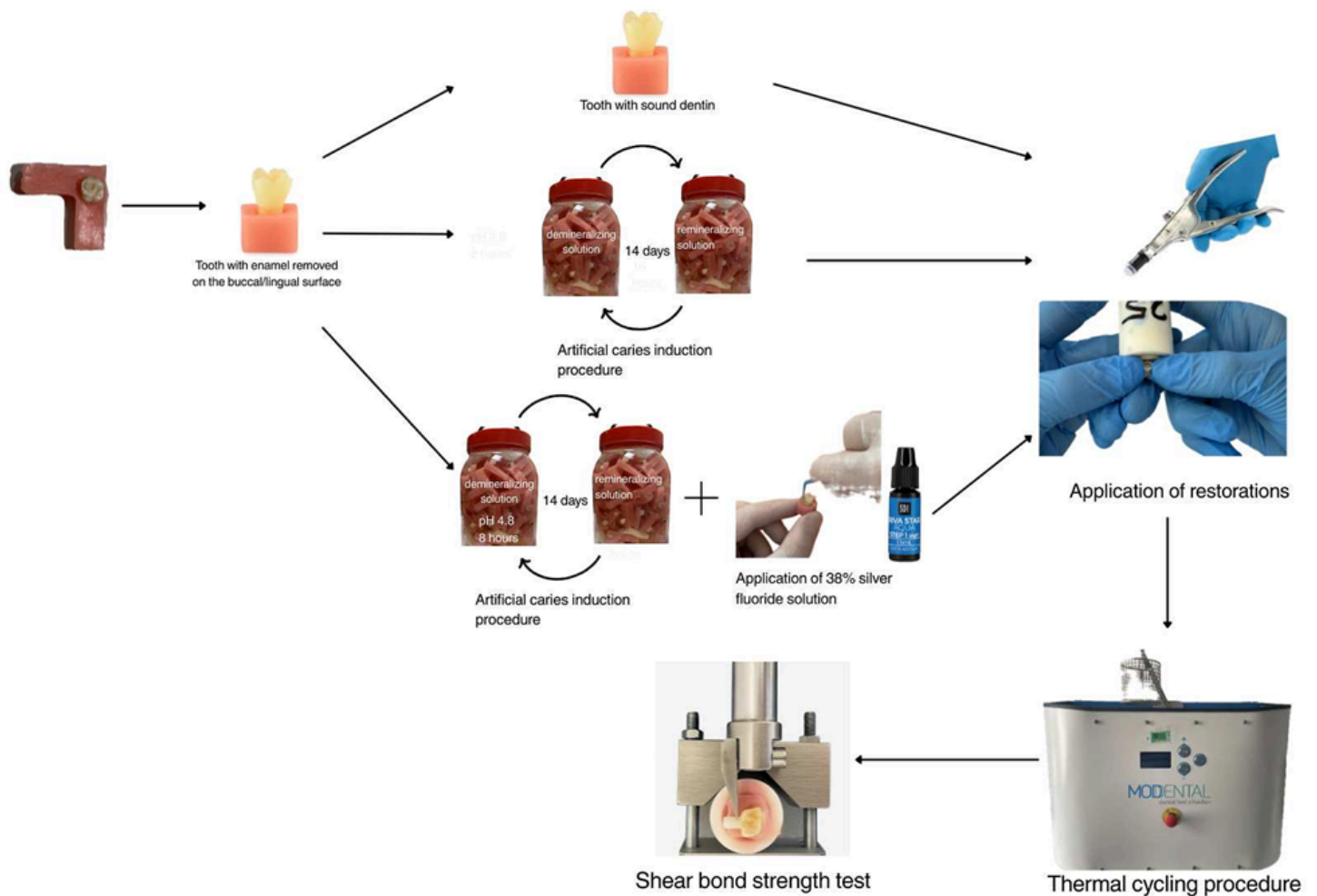


Figure 2

The flowchart of the study. **Legend:** Buccal and lingual surfaces of the primary molars were prepared by removing enamel under water cooling using a low-speed diamond saw to expose dentin. Specimens were assigned to sound dentin, artificially carious dentin, or artificially carious dentin treated with silver fluoride within each restorative material group. Following restorative procedures, half of the specimens were subjected to thermocycling. Shear bond strength testing was then performed on all specimens.



Figure 3

The mean shear bond strength values of the non-thermocycled and thermocycled specimens. **Legend:** Three graphs display bond strength values for each restorative material across different dentin surface conditions, including sound dentin, artificially carious dentin, and silver fluoride–treated carious dentin, with and without thermocycling. * $p < 0.05$ indicates a statistically significant difference between groups.

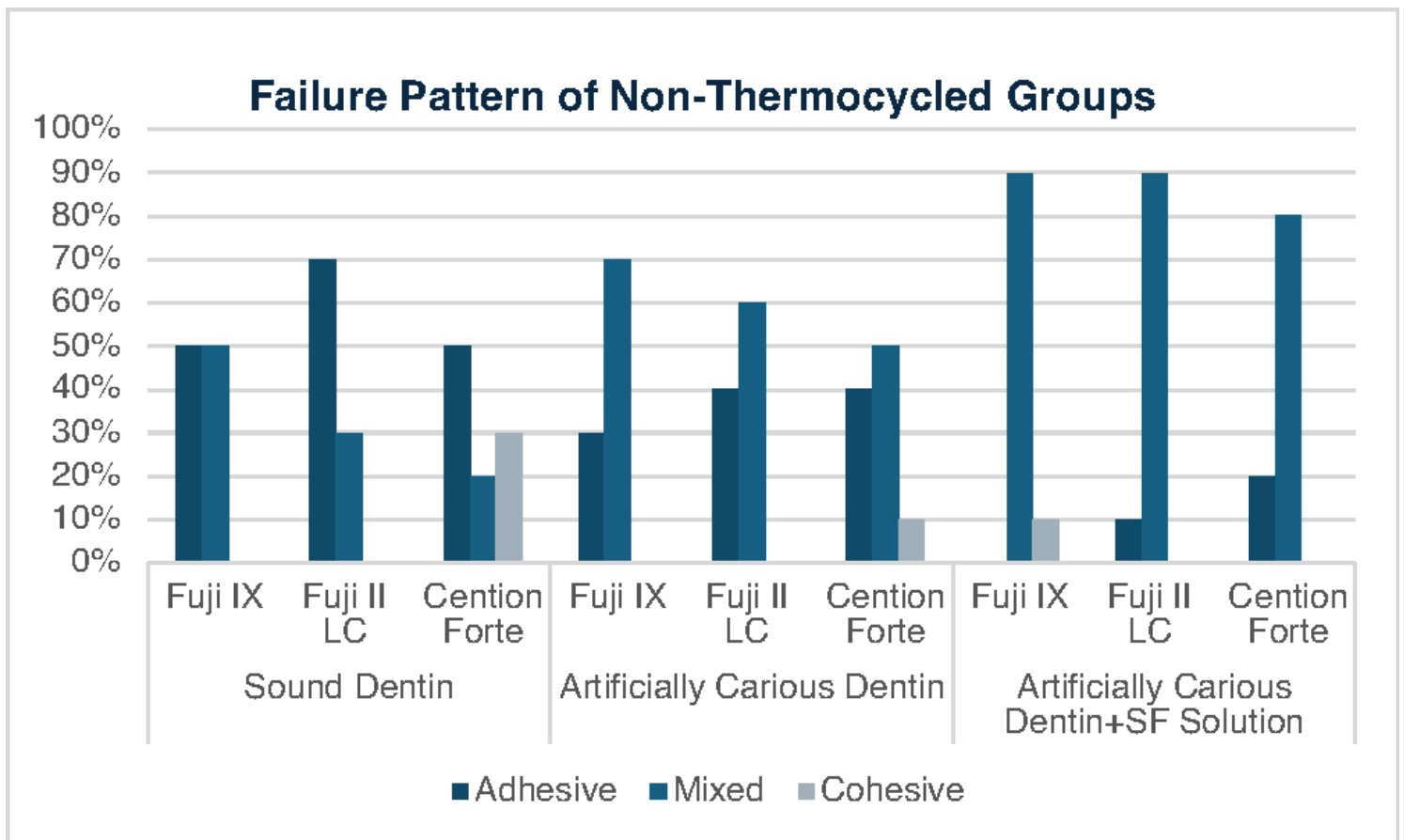


Figure 4

SEM images. **Legend:** Representative SEM images of the dentin–restorative material interface obtained from one specimen in each subgroup after gold–palladium sputter coating, under different surface treatment and aging conditions. FIX: high-viscosity glass ionomer cement (Fuji IX, GC, Japan); FII: resin-modified glass ionomer cement (Fuji II LC, GC, Japan); CF: alkasite-based restorative material (Cention Forte, Ivoclar Vivadent, Liechtenstein); SF: silver fluoride.

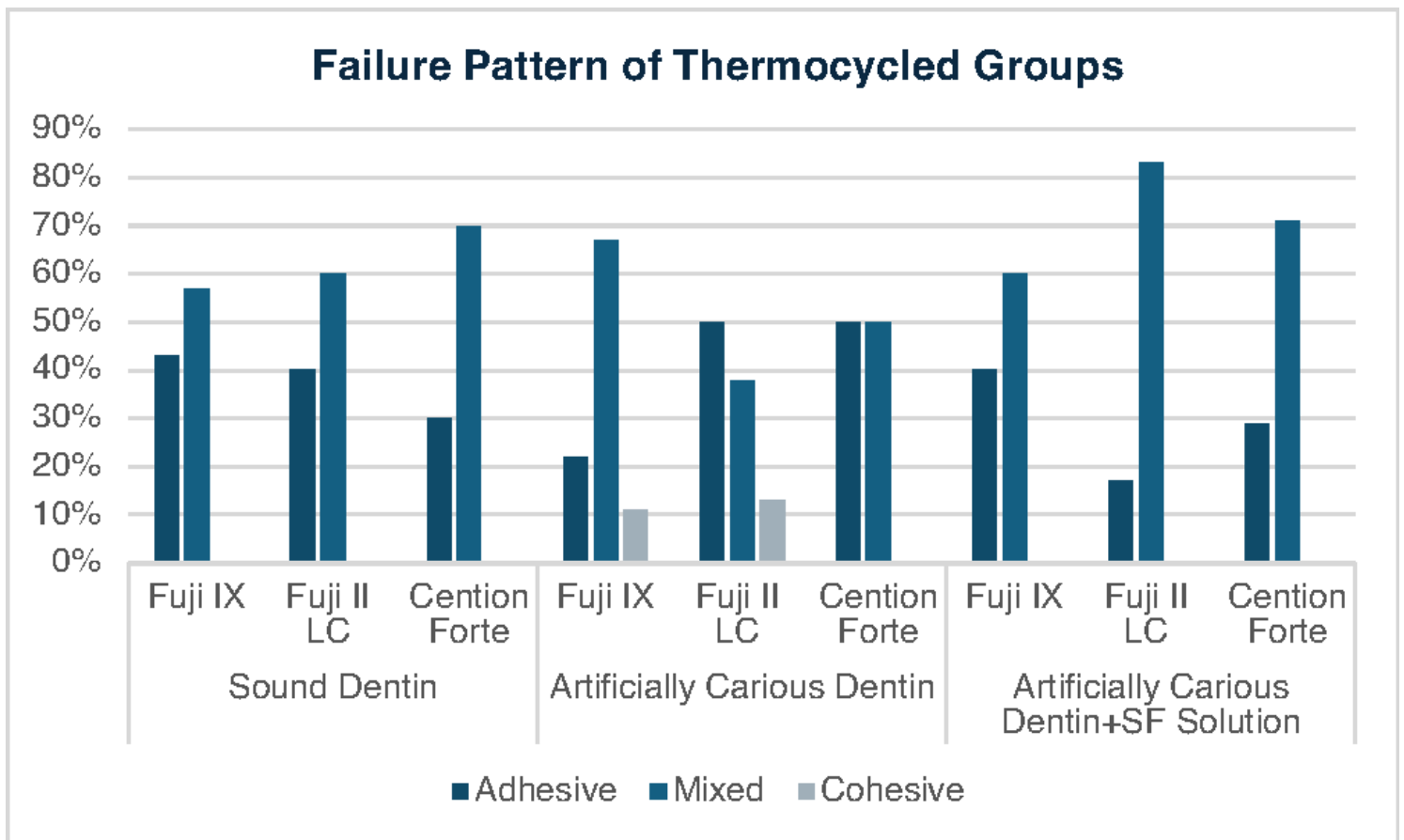
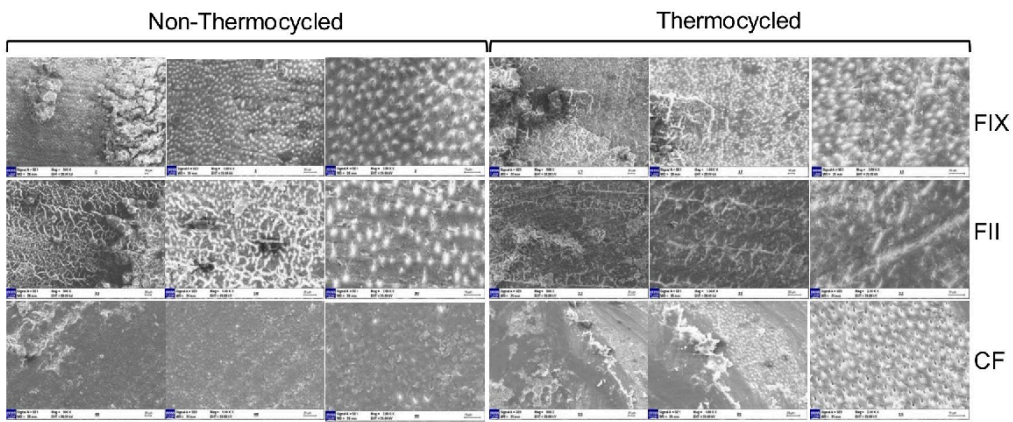


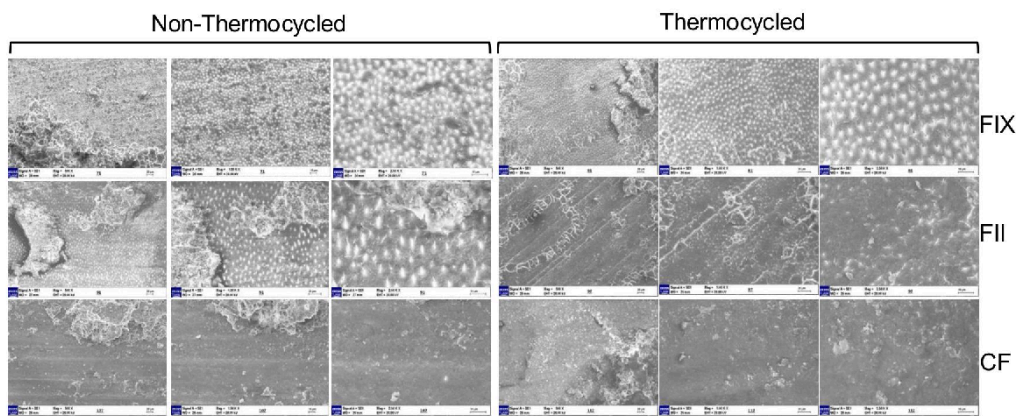
Figure 5

Failure Pattern of Non-Thermocycled Groups. **Legend:** Bar chart showing the percentage distribution of failure modes in non-thermocycled groups across different restorative materials and dentin surface conditions, including adhesive, cohesive, and mixed failures.

SOUND DENTIN



ARTIFICIALLY CARIOUS DENTIN



ARTIFICIALLY CARIOUS DENTIN + SF SOLUTION

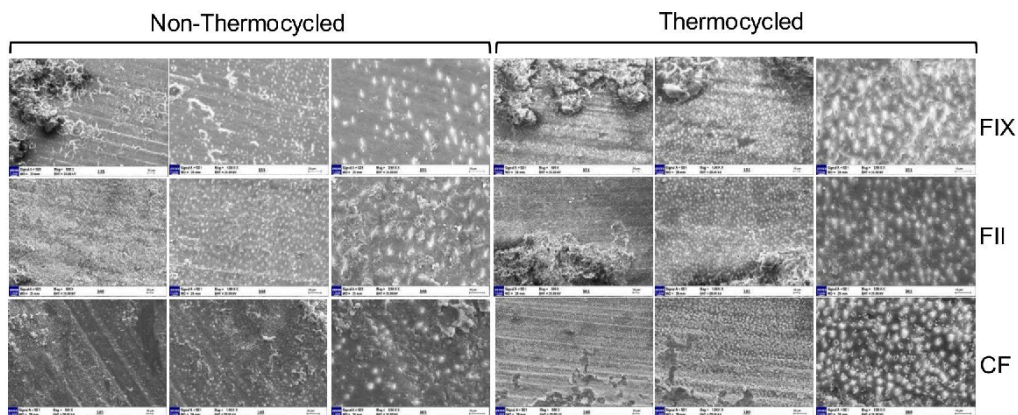


Figure 6

Failure Pattern of Thermocycled Groups. **Legend:** Bar chart showing the percentage distribution of failure modes in thermocycled groups across different restorative materials and dentin surface conditions, including adhesive, cohesive, and mixed failures.