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Original Article

Effect of 38% Silver Diamine Fluoride on Fracture Resistance of Leucite Reinforced Feldspathic Ceramic CAD/CAM Class I Inlay Restorations

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Abstract

Introduction: Silver diamine fluoride (SDF) is a topical agent that has recently gained popularity for its ability to stop and prevent dental caries.

Aim: The aim of this study was to evaluate the effect of SDF applied to class I cavities of extracted non-caries molar teeth on the fracture resistance of CAD/CAM block.

Materials and methods: Twenty eight extracted noncarious molars were selected for the study. They were divided into two groups (n=14 per group). In each tooth, a diamond head was used to create Class I cavities that were 2 mm deep and 2 mm wide. The fracture strength test was carried out by applying a force at a speed of 5 mm/min, while continuously increasing the long axis of the tooth at the point corresponding to the central fossa.

Results: SDF application did not have a statistically significant effect on fracture resistance in teeth restored with Class I cavities CAD/CAM blocks. The two groups did not differ statistically significantly according to the two-way ANOVA [mean fracture force (N) ± standard deviation: without SDF 1138.19±581.65 and with SDF 1067.93±555.65; p=0.712].

Conclusions: This study showed that SDF did not have either a positive or negative effect on the fracture resistance for restoration or easy application in cavities. Long-term clinical studies with different mechanical tests are needed for the safe use of SDF in pre-restoration cavities with CAD/CAM blocks.

Keywords

fracture resistance, restorations, silver diamine fluoride

INTRODUCTION

Dental caries remains one of the most common preventable diseases worldwide, although current methods like fluoride applications and fissure sealants are well known to be effective in prevention to a large extent.[1] Non-prevented and treated caries lesions' rapid progression causes pain and tooth loss, which adversely affects the quality of life.

Conventional treatment of dental caries is performed by removing the decayed tissue and placing a restoration whose longevity depends on its size and sealing.[2]

Removing noncarious tooth area to achieve an adequate bonding surface leads to fracture and failure of the restorations.[3] If the lesion requires restoration of over one-third of the intercuspal distance, the cusp fracture susceptibility increases.[3]

In recent years, the most accepted minimally invasive dentistry approach is to choose the treatment procedures that consider the natural tissues. One of the crucial principles of the minimally invasive approach is minimizing the risk of recurrent disease.[4]

Given the growing tendency for minimally invasive dentistry, partial restorations have become an alternative to conventional treatment procedures. These treatment options have enabled minimal invasive tooth preparation and consequently greater preservation of the dental tissues.[4] Partial restorations are classified as inlays (not covering the cusps), onlays (covering at least one cusp), and overlays (covering all cusps) according to the area to be restored. The use of CAD/CAM is important for reasons such as the difficulty of taking measurements in the conventional workflow, short treatment time (chair-side), accurate output profile with multiple axis cutting, and aesthetic formation.[5]

There is unequivocal evidence that secondary caries is the most common cause of restoration failure. It is essential to prepare the pathogenic non-bacteria cavity prior to restoration to avoid any secondary caries formation.[6]

A significant decrease in the prevalence and severity of dental caries has been reported with the introduction of fluoride-containing oral products.[7] However, it is also known that using oral products containing fluoride alone is not sufficient. In addition, economic status and diet are also known important factors of dental caries. With the increase in the consumption of free sugar and processed carbonated foods, inequalities in the prevalence of caries were observed, especially among groups with socioeconomic differences.[8-10]

It is known that silver compounds have been used in medicine for many years to control infections.[11] While silver has antibacterial effects, fluoride has a mineralizing effect. Silver and fluoride are combined to form a clear liquid, silver diamine fluoride (SDF), which has both antibacterial and remineralizing properties.[12-14] This compound inhibits the propagation of caries by inhibiting the Colony Forming Units (CFU) proliferation, especially of mono-species strains of *S. mutans* and *Actinomyces naeslundii*.[15] However, SDF increases the mineral content of dental hard tissues and promotes calcium absorption. Therefore, since SDF increases the mineral content of the teeth and supports calcium absorption, it is very effective in the treatment of caries lesions and causes high surface microhardness.[16,17]

SDF $[Ag(NH_3)_2F]$ is a topical agent that has recently gained popularity due to its effectiveness in stopping and preventing dental caries.[18] It allows for a more conservative tooth preparation because it is minimally invasive, arresting remaining decay and remineralizing the affected dentin.[19] SDF can also be used as a cavity disinfectant prior to restoration with the antimicrobial effect of silver and the remineralization effect of fluoride.[20]

Because SDF is an effective way of treating active lesions, its application has also been recommended during the SARS-Cov-2 pandemic period and has been useful in reducing the aerosol-generating procedures.[21] SDF has been approved by the US Food and Drug Administration (FDA) for use in the United States[22] and has been widely used for the prevention of primary tooth decay in children, the prevention of cavities and fissures of molars in adults, and the prevention of caries in the roots of teeth in geriatric patients[16,23,24].

Mineralization is a process that continues from birth to death. In this process, an inorganic substance is accumulated on organic matrix. Although the accumulation process of minerals is still not known, there are serious studies on this subject in the literature. Understanding the accumulation process of minerals will enable the prevention of mineralization-related disturbances.[25] When teeth are investigated, their anatomical structure consists of enamel, pulp-dentin complex, and cementum. Of these sections, the dentin section is a 70% mineralized section, and is also the largest section of the tooth.[26]

It is important to prevent tooth demineralization and saliva, fluoride therapy, diet and probiotic bacteria are included in the process. In particular, the neutralizing effect of saliva has been used to protect the tooth exposed to acid. It has been reported in studies that the pathogenesis of dental erosion is closely related to the buffering capacity and secretion rate of saliva.[27]

One of the most effective methods of preventing tooth decay is fluoridation of the teeth. Fluoridation of the teeth is carried out with the use of topical fluoride, such as toothpaste.[28] As a mineral, florapatite (FAP) is known to be the most common phosphate mineral. In the formation of FAP, the calcium in hydroxyapatite is replaced with fluorine and forms FAP. FAP requires ten calcium ions and six phosphate ions for every two fluoride ions. Therefore, if there is insufficient calcium and phosphate, then the remineralization process may not occur. FAP has much lower soluble properties compared to hydroxyapatite.[29,30] To prevent demineralization, fluoride acts as a catalyst that helps remineralize enamel with phosphate ions dissolved in saliva.[31,32] Also, the replacement of hydroxide with fluoride eliminates the vulnerability to lactic acid in hydroxyapatite, so that FAP $[Ca_{10}(PO_4)_6F_2]$ is not soluble in the mouth.[33] It is known how important mineralization is for fracture resistance, and tests have been developed to measure fracture resistance.[34-37]

Fracture resistance test was performed because we thought that it would change the dentinal tubules, elasticity, and fracture strength on the surfaces where SDF was applied. It is known that the bond strength between the dentin-applied cement with SDF and the dentin surface is higher than the bond strength between the cement without SDF and the dentin surface. Multiple previous studies showed the effect of SDF on the shear bond strength and micro-tensile bond strength of different restorative materials on sound dentin.[38] However, there is a research gap in the effects of SDF application on the fracture resistance of restorations in the available literature. Therefore, the null hypothesis of the present study is that SDF is not effective on fracture resistance of the feldspathic glass ceramic inlay restorations.

AIM

The aim of the study was to investigate whether the 38% SDF solution applied prior to under ceramic inlay restorations affects the fracture resistance of the restoration.

MATERIALS AND METHODS

Teeth selection

Twenty-eight human maxillary noncarious molars extracted for orthodontic needs and periodontal problems were used for the study. Ethical approval (Process No. 2021/427) from Istanbul Aydin University Ethics Committee and written informed consent from the participants were taken.

A digital caliper (Mitutoyo Corp, Tokyo, Japan) was used to standardize teeth selection of similar size and shape. The molars with a mesiodistal width of 12.0±0.5 mm and buccolingual widths of 10±0.5 mm, and similar mesiodistal and buccolingual dimensions at the cementoenamel junction (CEJ) were selected. Teeth that were cracked upon examination under a magnifying glass were excluded from the study. After cleaning the dental plaque, calculus, and periodontal soft tissues, the teeth were stored in 0.9% saline solution at 4°C.

In order to determine the number of samples, power analysis was performed using the G*Power (v. 3.1.9.7) program. The power of the study is expressed as 1-β (β=probability of type II error) and in general studies should have 80% power. Based on the study by Demirel et al.[39], biaxial flexural strength measurements were made according to the differences in the groups, and the effect size was determined as d=1.176 as a result of the calculation, and it was calculated that there should be at least 14 people in the groups to achieve 80% power at the α=0.05 level. Considering that there may be losses in the working process, it is useful to take this number above this number. The specimens were randomly divided into two groups (n=14 per group). Group 1: CAD/CAM restoration on Class I cavity without SDF application and Group 2: CAD/CAM restoration on Class I cavity with SDF application.

Cavity preparation

A single operator performed all cavity preparations **(Fig. 1)** with a standard procedure.[40]

A 45-degree angled, without undercuts at a depth of 2 mm occlusal cavities (Black I) were created, using high-speed rotation instruments and reversed conic and round diamond burs (#1151; KG Sorensen, Barueri, SP, Brazil) accompanied with continuous air-water cooling.

During the cavity preparations, a periodontal probe with a millimetric tip and the digital caliper was used to ensure that there was no deviation in the depth and dimensions of the cavity. In addition, the samples were examined for the same wall thickness of 3 mm and depth of 2 mm **(Fig. 1)**. Following that, the teeth were embedded 2 mm apically of the cementoenamel junctions in polymethylmethacrylate acrylic resin (PMMA).

An SDF solution (0.01 ml of 38%) was applied into the cavity of each study group's sample (n=14) for 1 minute with a micro brush. The excess was removed using cotton pellets, and the teeth were dried with compressed air. The study flowchart was shown in **Table 1**.

Computer aided design and restoration material

The prepared cavities were scanned at a 0-15 mm distance by an intraoral scanner (Omnicam, Sirona, Cerec MC XL, Frankfurt, Germany). Once the quality and accuracy of the recorded images were ensured, restoration margins were drawn in the 'Draw margin' section. Subsequently, the Computer-Aided Designs (CAD, network program: Sirona, Cerec SW, Frankfurt, Germany) of the teeth were performed. Then the ceramic blocks (G-Ceram, Gulsa, Izmir, Turkey) were placed on the metal rod of the Cerec scraping device (Cerec MC XL, Sirona Dental Systems, Bensheim, Germany) with the help of a special torque screwdriver. Under high-speed water cooling, the blocks were milled by diamond burs (Cylinder Pointed Bur 12S- Step Bur 12S, Sirona Dental Systems, Bensheim, Germany) **(Table 2)**.

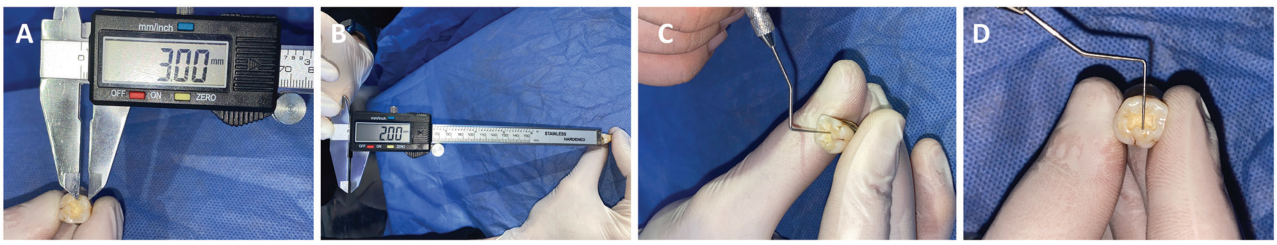

Figure 1. Measuring with a digital caliper, where the results were 3 mm.

Table 1. Study flowchart

Maxillary Non Caries Molars Extracted (n=14)	Maxillary Non Caries Molars Extracted (n=14)
Preparation cavities	Preparation cavities
Impression with Intra Oral Scanner	Impression with Intra Oral Scanner
Manufacture	Manufacture
Apply SDF	Without SDF
Cementation	Cementation
Instron Test Machine	Instron Test Machine

Table 2. Materials studied

Material **Generic names**	**Brand name and manufacturer**
Glass ceramic reinforced with leucite	Gceram, Gulsa, Izmir, Turkey
Self-adhesive resin cement	G-CEM LinkAce, GC Corporation Tokyo, Japan
Silane	G-Multi Primer, GC, Tokyo, Japan
Adhesive resin	G-Premio Bond, GC, Tokyo, Japan
%38 silver diamine fluoride	Advantage arrest, %38 silver diamine fluoride, USA
Digital caliper	Mitutoyo Corp, Tokyo, Japan
9% hydrofluoric acid	Porcelain etch, Ultradent, USA
37% phosphoric acid gel	Phosphoric acid, 3M-Espe, Germany
Intraoral scanner	Intraoral Scanner, Omnicam, Sirona, Cerec MC XL, Frankfurt, Germany
Milling device	Scraping Device, Cerec MC XL, Sirona Dental Systems, Frankfurt, Germany

Rigid crown material concentrates excess stress within the material. The low-hardness crown material transmits the stress to the cement and the underlying support tooth. The selection of the material closest to the tooth structure biomimetic is important. Crown material is the major determinant of maximum principal stress on a crown and it provides optimum durability with the selection of the cement material using leucite-reinforced glass ceramic.[41]

Clinical application of silver diamine fluoride

The tooth surface was kept dry during the application and then isolated. The solution was applied with a microbrush and allowed to absorb for 1 min. The excess was removed and rinsed with water. Skin should be immediately washed with soap and water if the SDF solution came in contact.

Ceramic restoration surface preparation

After cleaning with compressed air and water, the fitting surfaces of the inlays were etched with 9% hydrofluoric acid (porcelain etch, Ultradent) for 2 minutes according to the manufacturer's instructions, and washed for 2 minutes under pressurized running and air water spray and thoroughly for 1 minute in a cup with neutralizing powder (IPS Neutralizing powder, Ivoclar Vivadent, Schaan, Liechtenstein). Since etching with hydrofluoric acid leaves a significant amount of crystalline precipitate at the ceramic surface, inlays were cleaned using phosphoric acid (Ultra-etch, Ultradent) for 1 minute and ultrasonically cleaned in distilled water for 5 minutes.

Furthermore, surfaces were silanized (G-Multi Primer, GC, Tokyo, Japan) for 1 minute with disposable microbrush tips (KG Sorensen), excess silanol on the surface was removed under pressure with an oil filter, waterless and oil-free air freshener and dried in an oven (DI 500, Coltene Whaledent) for 5 minutes.

After silanization, adhesive resin G-Premio Bond (GC Corporation Tokyo, Japan) was applied. It was just applied to restoration surface, not polymerized.

Tooth surface

The enamel surfaces of the teeth were etched with 37% phosphoric acid gel (3M-Espe, Germany) for 20 seconds and then washed with water for 20 seconds.

Cementation

Class I inlays were luted adhesively (G-CEM LinkAce, GC Corporation Tokyo, Japan) according to the manufacturer's instructions. Self-adhesive resin cement was preferred because of the ease of application in the pediatric patient. The cement was light-cured for 20 seconds using a high-intensity LED curing unit operating at 1470 mW/cm^2, 430-480 nm (Elipar™ Deepcure-S, 3M ESPE, St. Paul, MN, USA). A total of 60 seconds of irradiation was made, 20 seconds from each surface. The reason we used dual cure resin cement is that chemical polymerization should start and contribute to the hardening in places where light penetration of the restoration is low. The samples were finished with diamond burs (KG Sorensen) at low speed with air-water spray and polished with aluminum oxide discs (SofLex; 3M ESPE).

Strain measurement and fracture resistance tests

All the specimens were stored in a distilled water at 37°C for 24 hours and subjected to thermocycling for a total number of 5000 cycles between 5°C and 55°C. The dwell time at each temperature was 30 seconds, and the transfer time from one bath to the other was 2 seconds. Then, specimens were mounted on the cyclic loading machine and filled with distilled water at 37°C to simulate oral temperature. After the aging process was completed, the teeth were embedded in the cylindrical pipes up to the enamel-cementum boundary for the fracture strength test. The samples were connected to the test device (Moddental, Esetron, Ankara, Turkey). The fracture strength test was carried out by applying a force at a speed of 5 mm/min and continuously increasing parallel to the long axis of the tooth at the point corresponding to the central fossa of the teeth. Values were recorded in newtons (N) when the fracture was observed. After the aging process was completed, the teeth were embedded in the cylindrical pipes up to the enamel-cementum boundary to test the fracture resistance, then the non-carious molars were embedded in the acrylic blocks up to the enamel cement boundary and the fracture resistance test was initiated. Thus, the applied force was evenly distributed on the teeth along the entire acrylic boundary, as in all fracture tests.

The fracture resistance of each specimen was recorded in newtons, and its fracture mode was classified according to the following patterns:

Favorable failures: repairable fractures of the teeth/restorations above the level of bone simulation;

Unfavorable failures: non-repairable fractures below the level of bone simulation.

The fractured samples were evaluated to determine the failure mode in each sample, following as reference the model classification according to the one proposed by Soares et al.[36] The four classification levels are listed in **Table 3** and the fracture patterns are presented as percentages.

Statistical analysis

All analyses were performed using SPSS 19 (IBM SPSS Statistics 19, SPSS Inc., an IBM Co., Somers, NY). Data were analyzed using an independent samples *t*-test and an ANOVA test, which is a type of statistical test used to determine if there is a statistically significant difference between two or more categorical groups by testing for differences in means using variance. Values of $p<0.05$ were considered as statistically significant.

RESULTS

Fig. 2 shows the fracture force between the groups with and without SDF. The 2-way ANOVA revealed a nonsignificant difference between the two groups [fracture force (N)±standard deviation: without SDF 1138.19±581.65 and with SDF 1067.93±555.65; $p=0.712$] **(Fig. 2)**.

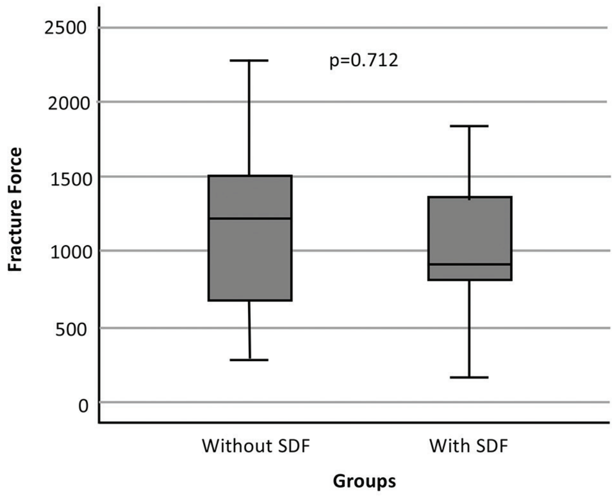

Figure 2. Fracture force between the groups with and without SDF.

Table 3. The fraction classification for the study

Code	Description
I	Isolated fracture of the restoration
II	Restoration fracture involving small tooth portions
III	Fracture involving more than half the tooth without periodontal involvement
IV	Fracture with periodontal involvement

DISCUSSION

Dental fracture is a common clinical problem in posterior teeth due to high bite forces or inappropriate contact with opposing teeth.[42] Also, it is well known that enlarging in the tooth structure loss increases the susceptibility to fracture.[3,42] To avoid extended tooth structure loss, minimally invasive dentistry (MID) and an approach focusing primarily on preventing and controlling oral diseases have been accepted.[43] Application of SDF has been recommended as part of this approach since it arrests and prevents the formation of new caries, either solely or under restorations.[1,19]

Another beneficial approach for caries arrest is Silver Modified Atraumatic Restorative Technique (SMART), which allows the SDF application on the same appointment before restoration. Alvear et al. reported that SMART helps to eradicate cariogenic bacteria and promotes remineralization.[44]

The effects of applying SDF under restorations on new caries development and the bond strength of restorative materials are well documented.[1] However, there is a research gap on its effect on fracture resistance of restored teeth. Therefore, the present study aimed to examine the effect of SDF use immediately before restoration on the fracture resistance of restored teeth. We applied SDF solution before the cementation procedure of the CAD-CAM ceramic restorations. During the cementation procedure, 37% phosphoric acid gel was applied only on the enamel surface for 20 seconds to increase adhesive strength and then washed with water for 20 seconds. SDF solution was still effective on the tooth surface after this procedure because normally, in SDF applications, it is applied in open cavities on the surface of the tooth and is waited for 1 minute. Excess SDF is removed with cotton. There is no need to take care that the material does not come into contact with water and contact with water does not affect the material.

From the perspective of MID, if the prevention has failed, then restorative procedures respecting the patient's natural tissues should be chosen.[43] Depending on the loss extent, various direct and indirect treatment options with composite resin and ceramic materials are available for caries of the posterior teeth.[45] It is worth noting that a restorative material while replacing the lost tooth structure should increase fracture resistance and provide marginal sealing.[46] However, polymerization shrinkage stress of the direct composite resins causes a gap between the cavity walls and the filling material. Consequently, bacterial infiltrations through the passage of fluids from this gap result in secondary caries.[46] Although this complication seems to be solved by lower polymerization shrinkage bulk-fill composites, they have inferior to conventional resins in terms of wear resistance and fracture toughness.[46] Indirect inlay/onlay techniques have been developed to overcome the mentioned problems of direct restorative procedures, enabling lesser tooth preparation and better preserving the dental tissues.[3] In this in vitro study, all-ceramic (leucite-reinforced glass-ceramic, Gulsa) restorative material was used because it is considered an excellent option for esthetic restorations.

Thermal cycling is an aging procedure that exposes the sample to extreme temperatures to simulate thermal stresses typically occurring in the mouth.[47] According to ISO TRY 11450 (1994) standards, immersing the specimens in water baths at least 20 seconds of 5°C and 55°C for 500 times and transfer time between baths of 5-10 seconds is a suitable accelerated aging method. However, this cycle number is insufficient to imitate the tooth bonding efficiency of the restoration.[48] Therefore, the specimens, in the present study, underwent 5000 thermo-cycles between 5°C and 55°C with a dwell time of 30 seconds and a transfer time of 15 seconds.

Shimizu and Kawagoe reported that recurrent caries did not develop after 26 months in the SDF-pretreated primary teeth.[49] Mei et al. found a reduction in secondary caries under the composite resin and glass ionomer cement restorations following conditioning with SDF.[16] Teeth roots were embedded in acrylic cylinders to mimic alveolar bone, preventing stress-intensification. The compressive load fracture test is beneficial for assessing the ultimate resistance to fracture of restored posterior teeth. The method enables quantifying the efficacy of different factors of restoration procedures.[42] The null hypothesis was accepted since the application of SDF did not affect the fracture resistance of restored teeth.

This in vitro study has some limitations in that it simulates clinical conditions. In fact, clinical fracture is due to fatigue caused by multidirectional cyclic loading. In this study, samples were subjected to thermal cycling aging protocol and then compression loads. In addition, adhesive resin cement is indicated for ceramic restorations. However, we used G-CEM LinkAce, a self-adhesive resin cement. It can be considered a limitation by affecting the integrity of the tooth-restoration complex. Therefore, we pre-treated the enamel before bonding to increase the bond strength of self-adhesive resin cements. It can be used as a fast cementation material of choice for patients who do not have coperitis in pediatric dentistry.

CONCLUSIONS

SDF did not have a significant, either negative or positive, effect in terms of fracture force following restoration and application in cavities in teeth tested in both groups. Long-term clinical studies with different mechanical tests are needed for the safe use of SDF in pre-restoration cavities with CAD/CAM blocks.

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Влияние 38 % фторида диамина серебра на сопротивление разрушению армированных лейцитом полевошпатовой керамики CAD/CAM реставраций-вкладышей класса I

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Резюме

Введение: Фторид диамина серебра (SDF) – средство местного применения, которое в последнее время приобрело популярность благодаря своей способности останавливать и предотвращать кариес.

Цель: Целью данного исследования было оценить влияние SDF, нанесённого на полости класса I удалённых некариозных коренных зубов, на устойчивость к разрушению блока CAD/CAM.

Материалы и методы: Для исследования были отобраны 28 удалённых некариозных моляров. Они были разделены на две группы (n=14 в каждой группе). В каждом зубе с помощью алмазной головки были созданы полости класса I глубиной 2 mm и шириной 2 mm. Испытание на прочность на излом проводилось путём приложения силы со скоростью 5 mm/min при непрерывном увеличении длинной оси зуба в точке, соответствующей центральной ямке.

Результаты: Применение SDF не оказало статистически значимого влияния на устойчивость к разрушению зубов, восстановленных с помощью CAD/CAM-блоков I класса. Две группы статистически значимо не различались по данным двустороннего дисперсионного анализа (средняя сила перелома (N) ± стандартное отклонение: без SDF 1138.19±581.65 и с SDF 1067.93±555.65; p=0.712].

Заключение: Это исследование показало, что SDF не оказал ни положительного, ни отрицательного влияния на сопротивление разрушению при реставрации или простоту применения в полостях. Для безопасного использования SDF в полостях перед реставрацией с блоками CAD/CAM необходимы долгосрочные клинические исследования с различными механическими испытаниями.

Ключевые слова

устойчивость к разрушению, реставрации, диаминфторид серебра