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Shear bond strength of resin-modified glass ionomer cement bound to mineral trioxide aggregate after various disinfection protocols

Deniz Yanık DDS, PhD[1] | **Kürşat Er DDS, PhD**[2] | **Alper Kuştarci DDS, PhD**[2]

[1]Department of Endodontics, Faculty of Dentistry, Antalya Bilim University, Antalya, Turkey
[2]Department of Endodontics, Faculty of Dentistry, Akdeniz University, Antalya, Turkey

Correspondence
Kürşat Er, Department of Endodontics, Faculty of Dentistry, Akdeniz University, Antalya, Turkey.
Email: qursater@hotmail.com

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Abstract
This study compared the effects of 3 different cavity disinfection protocols (CDP) on the shear bond strength (SBS) of resin-modified glass ionomer cement (RM-GIC) to mineral trioxide aggregate (MTA). One hundred eighty standard holes were prepared and filled with MTA. They then divided into 3 main groups based on the chosen time intervals (15 min, 24 h, and 72 h). Main groups were divided into 3 subgroups based on the CDP [chlorhexidine gluconate (CHX), ozone, laser, and control]. RM-GIC was applied on MTA after CDP for all groups. A universal testing device was then used for test and the data was statistically analysed. CHX showed significantly lower SBS values except ozone and laser than the control ($p < 0.05$). There were no statistically significant differences among the time intervals. As a result, CHX decreased the bond strength between the MTA and RM-GIC while ozone and laser had no negative effect.

KEYWORDS
cavity disinfection, laser, mineral trioxide aggregate, ozone, shear bond strength

INTRODUCTION

Mineral trioxide aggregate (MTA) is one of the calcium silicate-based cement and its usage is reported for many fields such as perforation repair, vital pulp therapies, regenerative procedures, root-end filling in endodontics [1]. It is a material of choice among the various perforation repair materials and root-end filling because of the stimulation of mineralised tissue formation and superior biocompatibility [2, 3]. The biological properties of MTA inducing hard tissue formation and its applicability to a humid environment are the most important reasons for the preference of MTA when coming into contact with delicate vital tissues such as pulp. However, there are some drawbacks of MTA that have clinical importance. Its main disadvantage is reported as difficulty in manipulation and long setting time, above all, MTA cannot provide sufficient flexural and compressive strength to endure high occlusal forces [1, 2, 4]. Since pulp capping and furcation repair materials are indirectly exposed to occlusal pressure, the material to be used in this area is expected to have high resistance [4].

Resin-modified glass ionomer cement (RM-GIC) has been developed with a modification of glass ionomer by adding polymerisable light-curing resin monomers [5]. RM-GIC is used as base material and cavity liner after perforation repair material to build a *"double seal"* for the protection of the pulp-dentin complex [1, 6]. It can be a proper alternative material to be used over MTA due to the fact that it is required lower compaction force while applying compared to conventional GICs [5–7]. Without strong compaction, the gentle bond between dentin and MTA is preserved and MTA is less likely to dislodge. Thus, we wanted to understand the bond strength (BS) between MTA and RM-GIC, unlike various studies [1, 3, 7–9] that generally focussed on the BS between MTA and composite resin or conventional GIC.

The bacterial load beneath the restorative material is one of the most important factors influencing pulp health [10]. To eliminate bacterial activity, cavity disinfection is considered an essential step of the restorative process. There are numerous cavity disinfection protocols (CDPs) used to reduce sensitivity, seconder caries, and pulpal inflammation [11]. Understanding the effects of CDPs ensures the choice of the right technique that does not reduce the BS of the materials to each other and dentin. The inadequate bonding between the materials and dentin compromises the success of the restoration [12].

Chlorhexidine gluconate (CHX) is the most frequently used cavity disinfectant and root canal irrigant due to its superior antibacterial ability and substantive properties [10]. It enhances the hybrid layer through the inhibitor effect on matrix metalloproteinase that contributes to the degradation of dentin extracellular matrix [10, 11]. Besides, because of adhesion into dentin, termed as substantivity, CHX highly affects the BS of restorative materials [10, 13, 14]. Ozone, with a strong oxidant effect, has been introduced in cavity disinfection due to its destructive effect on the cell wall and cytoplasm membrane of oral pathogen bacteria [15]. Previous studies [16, 17] evaluating the effect of ozone on BS have shown that it affects the polymerisation of adhesives. The laser technology can be used in cavity disinfection depending on the penetration ability, which is not in conventional techniques [2]. It contributes to cavity disinfection because of its smear-removing ability [18, 19].

MTA is generally covered with various restorative materials, when is used as a pulp capping or perforation repair agent [1]. Cavity disinfectants are used after the reparation of perforation or pulp capping procedures to sustain microbial control. However, most clinical studies have focussed on the effect of CDPs on dental tissues. For the integrity of the restoration, it is crucial to understand how the BS between locally applied perforation material and restorative material will be affected by the CDPs. Because even if there is strong BS between dentin and restorative material, the masticatory function might dislodge the perforation material and create the origin point of failure.

The aim of this study was to evaluate the shear BS, RM-GIC to MTA with CDPs at different time intervals. This is the first study to evaluate the effect of CHX, ozone, and diode laser on shear BS RM-GIC to MTA. We hypothesised that [1] cavity disinfection with CHX, ozone, and diode laser would reduce the BS between RM-GIC and MTA and [2] The BS between MTA and RM-GIC at the interval of 15 min would be lower compared to 24 h and 72 h.

MATERIALS AND METHODS

One hundred eighty cylindrical acrylic blocks ($n = 180$), each of which had a hole (5 mm in diameter and 2 mm in height) in the centre were prepared. The materials used in this study were MTA (MTA Angelus; Angelus, Londrina, PR, Brazil) and RM-GIC (Ionoseal; VOCO, Cuxhaven, Germany). MTA was mixed according to the manufacturers' instructions, and the holes of acrylic blocks were filled with MTA using a spatula and covered with a moist cotton pellet. The samples were divided into 3 main groups ($n = 60$) based on the different time intervals (*Group 1*. 15 min group, *Group 2*. 24 h group, and *Group 3*. 72 h group) after placement of MTA. For the groups that have the interval of 24 h and 72 h, to hamper to dry the surface of MTA the moist cotton was renewed. Then, each group was divided into 4 subgroups according to CDP. *Subgroup A*. CHX group, *Subgroup B*. Ozone group, *Subgroup C*. Diode laser group, and *Subgroup D* was the control group (without cavity disinfection).

In *Group 1*, specimens were covered with moist cotton for 15 min and CDP were performed. In *Groups 2* and *3*, MTA specimens were stored for 24 h and 72 h at 37°C and 100% humidity.

In *Subgroup A*. 2 ml %2 CHX (Klorhex; Drogsan, Istanbul, Turkey) was injected on the MTA surface for 1 min. After this procedure, specimens were gently air-dried for 10 s and RM-GIC was performed.

In *Subgroup B*. Gas ozone (Ozone DTA; Aproza, Hsin Chuang City, Taiwan) was applied with tip no.3 for 1.5 min with an output power of 10, and RM-GIC was applied.

In *Subgroup C*. An 810 nm wavelength diode laser (Picasso Dental Laser, AMD Lasers, Indianapolis, USA) with an output power of 1 W was applied for 1 min and RM-GIC was applied.

In Group D (control): MTA was prepared and RM-GIC was performed.

After all CDP were performed to all groups, RM-GIC was performed with the aid of a 4 mm height 3 mm diameter flexible plastic tube on the MTA and cured immediately. After the curing process, plastic tubes were gently removed.

A universal testing machine (Shimadzu, Kyoto, Japan) was used for the shear BS test. A crosshead speed of 0.5 mm/min was applied to each specimen by using a knife-edge blade until the bond between the MTA and RM-GIC failed. The results were recorded in Newton on the program Trapezium X Software (Shimadzu) and were converted to MPa. Shear BS in MPa was calculated by dividing the peak load at failure by the specimen surface area.

Statistical analyses were performed by using SPSS program (SPSS Inc, Chicago, USA). The means and standard deviations were calculated. The data were analysed by the Kolmogorov–Smirnov test to check a normal distribution. The shear BS values were analysed with analysis of variance (ANOVA) for the factors of curing time. The mean BSs of the groups were compared by using a one-way analysis of variance (ANOVA) and Tukey test at a significance level of $p<0.05$.

RESULTS

The mean and standard deviation values of shear BS are showed in Table 1. There were no statistically significant differences among the time intervals (Figure 1 and Table 1). This finding suggests that the curing time of the MTA does not affect the shear BS. CHX showed a significantly lower shear BS to MTA for *Groups 1* and *2* ($p<0.05$). It was observed that CHX, which was performed 15 min and 24 h after the MTA application, decreased shear BS. There was no statistically significant difference in shear BSs to MTA between *Subgroups A* and *D* (control) at the interval of 72 h. *Subgroups B* and *C* showed no significant difference compared to the control for all main time interval groups. The modes of failure were 62.2% adhesive mode, 13.3% cohesive, and 24.4% mix mode.

DISCUSSION

Our study reported that CHX decreased shear BS at the setting time of 15 min and 24 h, while ozone and diode laser had no effect. To maintain the hermetic seal and control bacterial contamination, the stabilisation of the interface between perforation repair and restorative materials is critical. On the other hand, cavity disinfection after the placement of MTA provides a *"double microbial seal"* after the disinfection of the region adjacent to vital tissues, for example, the perforation area. However, a CDP should not cause any deleterious effect on adhesion. We wanted to understand the effects of the early and late exposure of cavity disinfectants on BS between MTA and RM-GIC.

According to the results, the BS between MTA and RM-GIC decreased with the use of CHX as a cavity disinfectant. The first null hypothesis that cavity disinfection with CHX, ozone, and diode laser would reduce the BS between RM-GIC and MTA was partially confirmed. CHX causes a smoother surface on the MTA with a low volume crystalline formation or the inhibition of calcium hydroxide crystalline formation, subsequently, reduces BS [14]. This result was confirmed with another previous study [13] that reported the inhibition effect of CHX in the setting process of MTA. As a result of MTA degradation related to the setting process, the surface hardness and flexural strength of MTA were decreased [20, 21]. In this study, CHX did not reduce the BS between MTA and RM-GIC after the interval of 72 h. This can be explained by the fact that the final setting time of MTA is approximately 3 days, while its initial setting time is 2 h and 45 min [22].

The conflicting results in the literature can be attributed to the effects of CHX are not similar when its use on root dentin or coronal dentin. We recommended that cavity disinfection with CHX 15 min and 24 h after placement of MTA should be avoided and should be waited for the final setting duration.

Ozone is an important CDP because of its antibacterial properties. The results of this study revealed no effects of gaseous ozone as a CDP on BS between MTA and RM-GIC. The effect of ozone on BS to dentin and enamel has been the focus of several previous studies [23, 24]. Residual oxidants are well-known inhibitors that reduced the polymerisation of monomers and resin-tag penetration and cause the decreased BS to enamel and dentin [25, 26]. In this study, ozone did not reduce the shear BS between RM-GIC and MTA, and it can be concluded that ozone is reliable for the integrity of the restoration when performed to MTA as a cavity disinfectant. However, to understand the effects of ozone on the surface of MTA, more studies are needed.

According to the literature, the results of the effect of diode laser on BS are inconsistent [2, 19]. Saghiri et al. [2] reported that the diode laser was performed on dentin before MTA and decreased the BS between MTA and dentin. This may be attributed to the structural changes of the laser-irradiated dentin surface due to the ablation mechanism of the diode laser. On the contrary, another study [26] reported that diode laser increased BS to dentin due to removal of smear or debris layer. However, in our study, the diode laser was performed on the MTA surface

TABLE 1 Mean and standard deviation shear BS values of groups

	Group 1 (15 min)	Group 2 (24 h)	Group 3 (72 h)
	Mean (MPa) ± SD		
Subgroup A (CHX)	0.9 ± 0.2^{a,x}	1.2 ± 0.5^{a,x}	1.3 ± 0.6^{a,x}
Subgroup B (Ozone)	1.6 ± 0.4^{b,x}	1.6 ± 0.4^{a,b,x}	1.7 ± 0.4^{a,x}
Subgroup C (Diode laser)	1.2 ± 0.2^{a,b,x}	1.6 ± 0.6^{a,b,x}	1.6 ± 0.7^{a,x}
Subgroup D (Control)	1.7 ± 0.5^{b,x}	2.1 ± 0.7^{b,x}	1.8 ± 0.6^{a,x}

Note: To show the statistical differences; in the column, a and b and in the row, x superscripts has been used. Different superscripts indicate significant difference at 95% significance level ($p<0.05$).

Abbreviations: BS, bond strength; CHX, chlorhexidine gluconate.

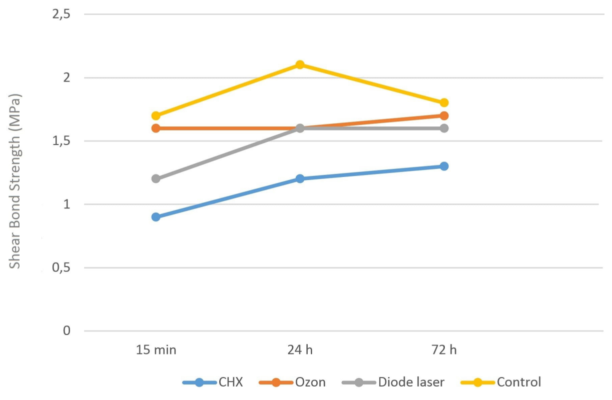

FIGURE 1 Shear BS values at 3 different time intervals

as a CDP and did not reduce the BS. It showed that the mechanical properties of the MTA surface were not negatively affected by the diode laser. More studies are needed to evaluate MTA surface changes under the influence of the diode laser.

The setting mechanism of MTA is based on the hydrophilic properties of MTA. The long setting time is a clinical disadvantage of MTA, thus, to reduce this process various additives have been used [13]. One of the aims of this study was to analyse the effects of the different time intervals on the BS. Our study did not show any difference between the BSs at the 3 different time intervals. Thus, the second null hypothesis that the BS between MTA and RM-GIC at the interval of 15 min would be lower compared to 24 h and 72 h was rejected. Several studies [7, 8, 27] showed the setting time of 45 min is enough to perform the conventional GIC.

BS is one of the crucial parameters for the quality of restoration. A previous study [9] that examined the BS between RM-GIC and MTA reported 3.56 MPa. This result is higher than ours that showed the shear BS between MTA and RM-GIC was 0.9–2.1 MPa. To obtain the most realistic results, in our study, the samples were tested immediately after the final light-curing process. Because in a clinical scenario, the teeth are loaded with occlusal forces immediately after the treatment. However, in this previous study [9], the samples were kept for 28 days until to test. The discrepancy in MPa values between the 2 studies can be explained by this difference in methodologies. The literature reported the BS between MTA and conventional GIC was in the range of 3 to 9.33 MPa [8]. The BS between resin composite and MTA was 0.9–2.5 MPa [3]. The BS of conventional GIC to MTA is higher than that of RM-GIC and resin composite to MTA. As previously concluded in the literature, a BS of approximately 17–20 MPa is needed to create a gap-free restoration [28]. However, according to obtained MPa values in our study (0.9–2.1 MPa) or as concluded in a previous study (3.56 MPa) [9], we recommend that to use of RM-GIC on MTA should be carefully considered in terms of BS.

In this study, the highest rate of failure mode was adhesive mode (62.2%). The low BS observed in our study explains the highest rate of adhesive failure. A previous study [9] that examined the BS between RM-GIC and MTA found the highest rate of failure (53.3%) was the mix type. This difference can be attributed to the different crosshead speeds and the duration before the shear test is performed. Our study applied the shear test immediately after the light-curing process, while the other study kept the samples for 28 days before the test process. Our crosshead speed was 0.5 mm/min, it was 1 mm/min in another [9].

The shear BS test that applies a force parallel to the bonding surface is used to examine the BS of the materials. During the loading of the force, heterogeneous stress areas on the fracture surface may result in inaccurate results and cohesive failure. To eliminate inaccurate results, crosshead speeds of 0.50 and 0.75 mm/min are preferable in the shear BS test [29]. Thus, in our study, the load was applied with a crosshead speed of 0.5 mm/min.

Resin composite, conventional GIC, and RM-GIC are used directly over MTA in clinics, however, it should be emphasised that these 3 have drawbacks. If resin composite is performed over fresh MTA, the process of etching and rinsing will damage the mechanical properties of MTA [3, 8, 9]. Conventional GIC needs more intense compaction forces compared to RM-GIC [8]. RM-GIC has low BS that compromised the success of restoration as concluded in this study. However, the results of in vitro studies do not represent clinical conditions. More studies are needed to accomplish an optimum restoration strength with an ideal material.

In this study, we tried to simulate clinical scenarios as far as possible, in vitro researchers always have limitations and do not fully represent clinical conditions. The cavity surface represented in this study was flat and contained 2 different materials. However, in clinical conditions, this surface is not completely flat and can be mentioned the movement of a complex that consisted of MTA, RM-GIC, and dentin, not only restorative materials. Further studies are needed to understand the BS of conditioned or unconditioned MTA with ozone, diode laser, and CHX.

CONCLUSIONS

Within the limitations of this in vitro study, it might be concluded that ozone and diode laser did not significantly affect the shear BS between MTA and RM-GIC. The usage of CHX as a cavity disinfectant 15 min and 24 h after MTA application reduced BS between MTA and RM-GIC.

According to the results, it is better to postpone the restoration with RM-GIC after CHX disinfection for more than 24 h.

AUTHOR CONTRIBUTIONS

D.Y., K.E., and A.K. performed the research. D.Y. and K.E. designed the research study. D.Y. contributed essential reagents or tools. D.Y., K.E., and A.K. analysed the data. D.Y. and K.E. wrote the paper.

CONFLICT OF INTEREST

The authors have no declared financial interests in any company manufacturing the types of products mentioned in this article.

ORCID

Deniz Yanık https://orcid.org/0000-0001-5676-0293
Kürşat Er https://orcid.org/0000-0002-0667-4909
Alper Kuştarci https://orcid.org/0000-0002-4942-3739

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