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Original Paper

Bond strengths of two conventional glass-ionomer cements to irradiated and non-irradiated dentin

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This study evaluated the influence of irradiation on the dentin shear bond strength of two conventional glass ionomer cements (GICs). Thirty extracted molars were bisected in the mesio-distal direction. One-half of 20 teeth were irradiated with 60 Gy (5 days/week) for 6 weeks, and then GIC was placed on the irradiated dentin surface (Groups A1, B1). For the other halves of these tooth specimens, the GICs were first placed on their dentin surfaces and then the specimens irradiated (Groups A2, B2). The remaining 10 teeth were bisected and used as non-irradiated controls (Groups C1, C2). The GIC-dentin shear bond strengths were examined. Groups A2 and B2 had significantly lower bond strengths than groups A1, B1, C1, and C2 ($p<0.05$). No significant differences were found among groups A1, B1, C1, and C2 ($p>0.05$). In conclusion, irradiation may have an adverse effect on the bond strength of GICs depending on the application sequence.

Key words: Irradiation; Glass-ionomer cements; Adhesion

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INTRODUCTION

Radiation caries is a well-known, indirect side effect of head and neck radiotherapy[1]. However, the pathomechanism of radiation-induced caries remains controversial. Studies on the mechanical properties of irradiated teeth are often hampered by "nonphysiological" conditions, such as the application of mechanical forces that exceeded the elastic limit of the samples[2,3]. Nonetheless, radiation caries seems to originate from radiation-induced defects in the amelodentinal junction and changes in the oral flora[4-6] due to reduced salivary flow rate and poor oral hygiene[7].

Besides irradiation-induced xerostomia, the effect of irradiation on dental hard tissues may be an important factor in radiation caries. Studies have reported on the physical and chemical changes in enamel after radiotherapy, which are a direct consequence of the irradiation treatment. For dentin, a significant reduction in microhardness is observed after irradiation[8,9], and then accompanied by reduced stability of the amelodentinal junction after radiotherapy[2]. Therefore, radiation-induced changes in the crystalline structure must be considered in addition to the hyposalivation-induced changes in the oral environment[8].

Radiation caries involves both dentin and enamel, and that it tends to first affect the cervical and incisal edges of the teeth[4,10]. Changes in the teeth are typically observed several months after irradiation[2], and crown amputation may occur due to circumferential caries at the cementoenamel junction[11].

The treatment of radiation caries can be extremely demanding on both the patient and dentist. This is exacerbated by restorative materials not holding up very well in the altered oral environment[4] due to the reduced stability of the dentoenamel junction after radiotherapy[2]. Glass ionomer cements (GICs) are tooth-colored materials that have several clinical advantages over other restorative materials. These include physicochemical bonding to the tooth structures and long-term fluoride release. Their desirable properties make them useful materials in the restoration of carious lesions, especially in low-stress areas such as buccal and oral smooth surfaces and cervical cavities[12-14]. Due to the irreversibility of radiation-induced xerostomia, the remineralization effects of saliva may not be expected in irradiated patients[9]. Therefore, GICs are important restorative materials for these patients.

The bond strength of adhesive systems to irradiated dentin has been described in only a few reports[15,16]. Gernhardt *et al.*[16] found that the reduced microhardness of irradiated dentin did not seem to influence the dentin bond strength of adhesive systems. On the contrary, Bulucu *et al.*[15] reported that irradiation could have an adverse effect on bond strength, depending on the type of adhesive. Adhesive resins bond to dental hard tissues microme-

chanically, whereas conventional GICs bond chemically[17,18]. Therefore, the irradiation sequence may exert more influence toward the dentin bond strength of GICs as compared to the resin adhesives. However, dental literature to-date lacks data on the effects of irradiation on the dentin bond strength of GICs.

Therefore, the purpose of this study was to evaluate the effects of pre- and post-irradiation application on the shear bond strength of two conventional glass ionomer cements to dentin: Fuji IX (FIX) and Ketac Molar Easymix (KME).

MATERIALS AND METHODS

Preparation of dentin specimens

Thirty freshly extracted, sound human molars were used. The teeth were cleaned of debris and stored in phosphate-buffered saline at room temperature for up to 3 months until the experiment. The teeth were bisected in the mesiodistal direction with a diamond disk under water cooling. Subsequently, the exposed dentin surface of each tooth was polished with 200-, 400-, and 600-grit silicon carbide abrasive papers. The 60 specimens were embedded in a chemical-polymerizing acrylic resin (Imicryl, Konya, Turkey). Care was taken to keep the experimental surfaces free of resin (Fig. 1).

The specimens were randomly assigned to six test groups (n=10) as follows:

- Group A1: Irradiation followed by restoration with FIX (Pre-irradiated group)
- Group A2: Restoration with FIX followed by irradiation (Post-irradiated group)
- Group B1: Irradiation followed by restoration with KME (Pre-irradiated group)
- Group B2: Restoration with KME followed by irradiation (Post-irradiated group)
- Group C1: FIX restoration without irradiation (non-irradiated control group)
- Group C2: KME restoration without irradiation (non-irradiated control group)

In groups A1 and B1, the dentin surfaces were irradiated with a total dose of 60 Gy applied in fractions over 6 weeks, and then the GICs were placed at the center of the flattened dentin surfaces by packing the materials into cylindrical plastic tubes with an internal diameter of 3 mm and a height of 4 mm (Fig. 1). In groups A2 and B2, the GICs were first placed on the flattened dentin surfaces and then

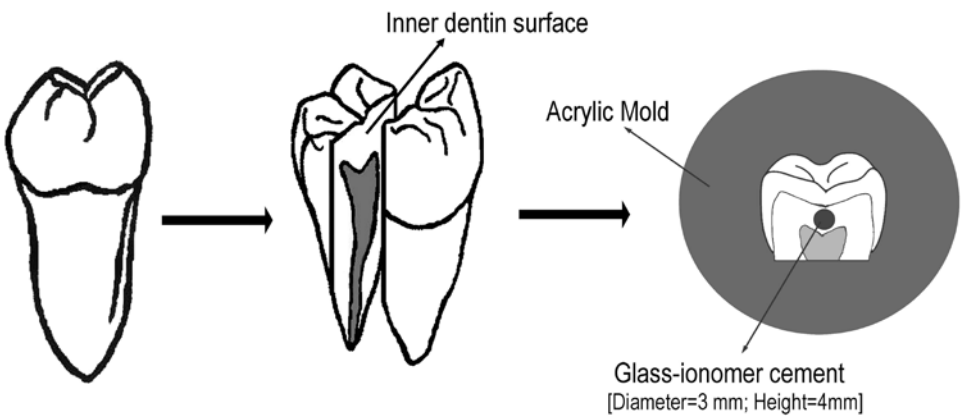


Fig. 1 Schematic illustration of the specimen preparation process.

Table 1 Manufacturers, compositions, powder-liquid ratios, and batch numbers of the tested materials

Convetional GIC Materials	Conditioner	Composition	P : L ratio	Manufacturer
Ketac Molar Easymix Powder: 212344 Liquid: 212425	Ketac Conditioner (25% polyacrylic acid) for 25 s	Powder: Al-Ca-La fluorosilicate glass, 5% copolymer acid (acrylic and maleic acid) Liquid: Polyalkenoic acid, tartaric acid, water	3.0 : 1.0	3M ESPE, St. Paul, MN, USA
GC Fuji IX Powder: 0509221 Liquid: 0509211	GC Cavity Conditioner (20% polyacrylic acid) for 10 s	Powder: Alumino-fluorosilicate glass Liquid: Polyacrylic acid, polybasic carboxylic acid, water	3.6 : 1.0	GC, Tokyo, Japan

the teeth irradiated using the same protocol. In groups C1 and C2, the GICs were placed and the teeth were kept as non-irradiated controls. Two improved conventional GICs (FIX and KME) were used in this study. Their compositions and powder-liquid ratios are listed in Table 1.

In groups using KME, 25% polyacrylic acid conditioner was applied to the dentin surface for 25 seconds before the GIC was placed on the dentin surface[19,20]. As for groups using FIX, 20% polyacrylic acid conditioner was applied to the dentin surface for 10 seconds[20]. After rinsing the conditioner with distilled water for 10 seconds, each tooth was gently blot-dried before placement of the GIC. The GICs were applied at the center of the flattened dentin surfaces by plastic tubes. The specimens were allowed to set for 10 minutes within the plastic tubes to ensure completion of the initial setting reaction. After the plastic tubes were carefully removed, the specimens were immersed in water in a plastic container. The water level was adjusted such that it covered the surfaces (about 0.5 cm over) of the specimens.

Before the shear bond test, the specimens were immersed as described above at room temperature without any change of water for 6 weeks. When it was perceived that the water level was lowered as a result of evaporation, water was added accordingly. Storage time for all test groups was set at 6 weeks. All specimens were prepared by the same operator.

Application of irradiation

Specimens were irradiated at the Department of Radiation Oncology, School of Medicine, Karadeniz Technical University (Trabzon, Turkey). During irradiation, the teeth in acrylic resin blocks were placed in a 25-cm^2 plastic container filled with water to a level 0.5 cm above the resin blocks to ensure dose homogeneity. Irradiation was performed with a linear accelerator (Saturne 43 Linac, GE Medical Systems S.A., Buc Cedex, France) using a single anterior field and at a source-water surface distance (SSD) of 100 cm. A total dose of 60 Gy was delivered as 2-Gy/day fractions, 5 days per week (conventional fractionation schedule), for a period of 6 weeks for all the test groups.

Shear bond strength test

Specimens were mounted in a universal testing machine (Lloyd Instruments, Fareham, Hampshire, UK). A crosshead speed of 1 mm/min was applied to each specimen until the bond between the dentin and GIC failed. The values were calculated as Newtons (N) and converted to MegaPascals (MPa).

Fourier transform infrared spectroscopy analysis

Chemically cured, resin-free GICs (Fuji IX and Ketac Molar Easymix) were placed in a stainless steel mold (5 mm diameter, 2 mm height). Five specimens were prepared for each group. A total dose of 60 Gy was delivered as 2-Gy/day fractions, 5 days per week (conventional fractionation schedule) to half of the specimens, for a period of 6 weeks. Specimens were stored in water until Fourier transform infrared spectroscopy (FTIR) analysis. After 6 weeks, both irradiated and non-irradiated specimens were pulverized into fine powder with a mortar and pestle. Fifty micrograms of the ground powder was mixed with 5 mg of potassium bromide powder (Carlo-Erba Reagenti, Milan, Italy), and the absorbance peaks were recorded using FTIR (Mattson 1000). For interpretation and comparison of the recorded FTIR spectra, the region of 450 and 4000 $cm^{-1}$was chosen.

Statistical analysis

The Kolmogorov−Smirnov test was used to evaluate trends of prevalence in data. After confirming the data for each test group, parametric and non-parametric tests were performed. Two-way ANOVA followed by the Bonferroni *post hoc* test were used to compare the shear bond strengths of the two GIC materials and among the three treatment protocols. Significance level was set at α=0.05.

RESULTS

Table 2 presents the means and standard deviations of shear bond strength of the test groups in this study.

There were no significant differences in adhesion

Table 2 Means and standard deviations of the shear bond strength data (MPa) of the test groups in this study (n=10)

Conventional GIC Materials	Groups		
	Non-irradiated (control group)	Pre-irradiated	Post-irradiated
Fuji IX	3.2±0.6 [a]	3.6±0.8 [a]	1.9±0.4 [b]
Ketac Molar Easymix	3.4±0.7 [a]	3.2±0.8 [a]	1.9±0.4 [b]

The mean difference is significant at 0.05 level.

Groups identified with the same superscripts are not significantly different (p>0.05).

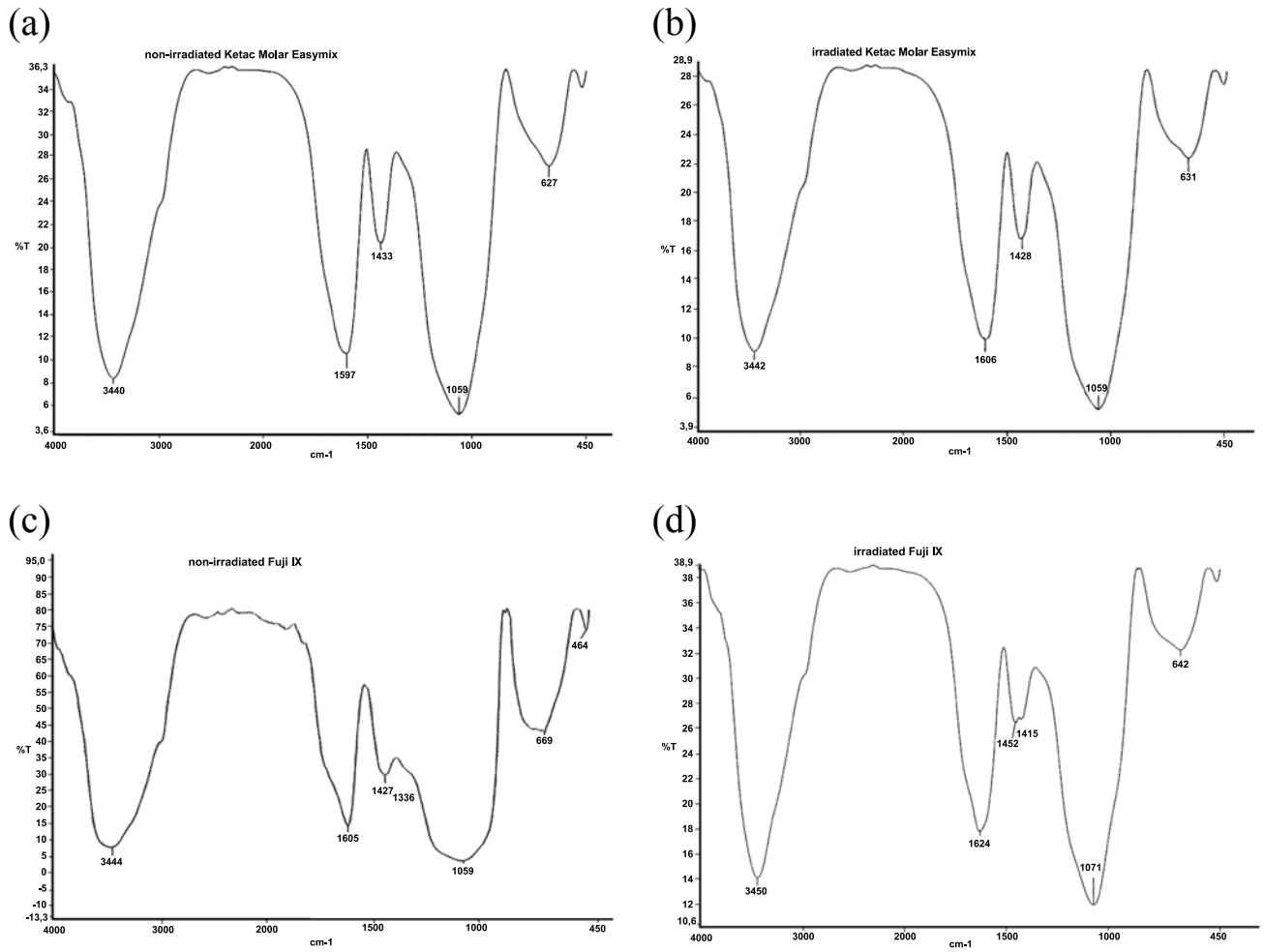


Fig. 2 FTIR spectra of both irradiated and non-irradiated GICs. The FTIR spectra of GICs showed a strong broad band at about 1059 cm^{-1} attributable to Ca−O, Al−O, and Si−O stretching vibrations arising from unreacted glass and calcium aluminum fluorosilicate glass ionomers. Absorption at about 1430 cm^{-1} showed the C−O stretching band of the carboxylate salts of the polyacid. Absorption at about 1605 cm^{-1} was assigned to the stretching vibration of carboxyl group, and 1605 cm^{-1} band in spectra showed that calcium polyacrylate, aluminum polyacrylate, or silicon polyacrylate had been formed. In addition, the 3440 cm^{-1} band in spectra was assigned to the water band, which meant that O−H (or −COOH) group probably did not react.

to dentin between the two types of conventional GICs (FIX and KME) within each treatment protocol ($p>0.05$). The mean shear bond strengths for the post-irradiated groups (A2, B2) were significantly ($p<0.005$) lower than the pre-irradiated (A1, B1) and control (C1, C2) groups. No significant differences were found between the pre-irradiated (A1, B1) and control (C1, C2) groups ($p>0.05$).

Figures 2a−d show the FTIR spectra of the non-irradiated and irradiated GICs (Fuji IX and Ketac Molar Easymix) between 450 and 4000 cm^{-1}. The positions of peaks and troughs in the different spectra were all consistent with an acid-base neutralization process. According to FTIR analysis results, there were no differences between the irradiated and non-irradiated GICs.

DISCUSSION

Radiotherapy pertains to the delivery of the correct radiation dose to the tumor mass. The dose absorbed in radiotherapy is expressed in SI unit, the gray (Gy)[11]. The wide-ranging side effects of ionizing radiation to the head and neck region are well-known and are related to cumulative doses that range from 50 to 70 Gy delivered over 5 to 7 weeks[21]. Roothwell[22] stated that most orofacial complications are dose-dependent and severe side effects occur when doses exceed 45 Gy. In this study, the specimens were irradiated with 60 Gy, applied

fractionally over 6 weeks, which corresponded to standard clinical procedures[9]. In addition; the specimens were irradiated in water to mimic the clinical setting of therapeutic irradiation. However, it should be highlighted that inter-individual effects of radiotherapy may vary tremendously depending on differences in salivary flow, microbial composition, and dietary changes.

In principle, conventional glass ionomers are materials that are self-adhesive to tooth tissue without any surface pretreatment. The polyacrylic acid in GICs can have a decalcifying effect on dentin. On this basis, there is no need to pretreat dentin with a decalcifying agent before a GIC is applied[17]. Nonetheless, pretreatment with a weak polyalkenoic acid conditioner significantly improves their bonding efficiency[20,23]. Therefore, in this study, a conditioner was applied to the dentin surfaces before the GICs were bonded to the latter.

Retief[24] reported that the storage medium of extracted teeth before test specimen preparation is an important factor that influences the results of bond strength studies. Common storage media include formalin, chloramine, ethanol, saline, thymol, and sodium azide[24]. In this study, the teeth were stored in phosphate buffered saline[19,20] at room temperature[20] until they were used at the laboratory. Since all the teeth for all the test groups in this study were kept in the same storage medium, it was assumed that differences due to storage medium among the test groups were precluded. Additionally, in non-irradiated control groups, the bond strength values of FIX (3.2 MPa) and KME (3.6 MPa) to dentin were similar to previous reports[25,26]

The shear bond strength of GIC to dentin has been reported to be in the range of 3−4 MPa after 24 hours[25,26]. However, GICs have a double-setting reaction whereby the initial setting occurs within the first four minutes. The subsequent reaction is much slower. This second part of the self-adhesion mechanism can continue for weeks — or even months[27]. Therefore, the timeframe within which GIC-dentin shear bond strength is measured is an important consideration. However, contrary to the current teaching that early exposure to water will weaken glass ionomer restoratives, Leirskar *et al.*[28] reported that the bond strength of an improved GIC (Fuji IX) to dentin increased after immersion in water for 8 weeks. Similarly, Wang *et al.*[29] also reported that the bond strength of another improved GIC, Ketac Molar, was not adversely affected after immersion in water at the end of 4 weeks. In this study, the experimental timeframe was set as 6 weeks due to the irradiation sequence. All specimens were stored in water during the 6-week timeframe until the shear bond test.

Studies dealing with irradiation effects on dental hard tissues have focused mainly on enamel as the substrate. Although irradiated dentin is a clinically relevant bonding substrate, little is known about the direct effects of ionizing radiation on dentin[1,11]. Grotz *et al.*[30] reported that the mechanical properties of dentin seemed to be less affected by irradiation than enamel. It should be mentioned that direct radiogenic effects may affect the mechanical stiffness of dentin[8,9]. However, under radiotherapy conditions, irradiation obviously has only a minor effect on the mechanical properties of dentin[30]. Zach[31] reported that irradiated teeth showed no alterations in crystallinity or calcium-phosphorus ratio. Similarly, White *et al.*[32] also reported that gamma irradiation did not alter the structure nor the function of dentin as determined by permeability, FTIR and UV-Vis-NIR spectroscopy. In this study, the effect of gamma irradiation on set GIC materials was examined by FTIR spectroscopy. It was found that the spectra of irradiated and non-irradiated specimens were not different from each other (Figs. 2a−d). In summary, it was shown that set GIC materials were not affected by gamma irradiation, as seen from the recorded FTIR spectra of this study. Similarly, neither was the crystallinity nor calcium-phosphorus ratio of dentin altered after gamma irradiation[31]. Taken together, the low bond strength of post-irradiated groups (A2, B2) could not be explained by the negative effect of irradiation on dentin or glass ionomer cements.

The post-irradiated groups (A2, B2) had significantly lower bond strengths. By contrast, the non-irradiated (C1, C2) and pre-irradiated (A1, B1) groups had similar bond strengths. In other words, GIC application after dentin irradiation did not affect the bond strength. A probable explanation for these results would be that irradiation directly influenced the setting reaction of GIC and its bonding to dentin.

The setting reaction of GIC is a long-drawn affair. Long-term interaction occurs through the slow diffusion of some elements of glass ionomer cement through dentin. Final maturity may not be reached for weeks or months for the fast-setting and slow-setting cements respectively[27]. Initial setting is caused by the interaction of calcium ions with polyanions. When a GIC comes in contact with the dentin surface, the polymer is thought to bond to the surface chemically, producing adhesive bonds between the two surfaces[18]. Irradiation seems to interfere with the chemical adhesion of GIC to dentin. As stated by Cheung *et al.*[33], gamma irradiation can cleave the chemical bonds of polymers — which means that radiation may break the chemical bonds, thereby weakening the materials. Therefore, gamma irradiation may disrupt/affect the chemical exchange lasting for weeks (long-term interaction) or bonding between the leached ions

from the setting glass ionomer matrix and the calcium and phosphate ions in dentin. In this study, irradiation was applied a day after GICs were bonded to the surfaces of dentin in post-irradiated groups (Groups A2, B2). As a result, incomplete acid-base reaction might have been caused by the application of gamma irradiation for 6 weeks.

Preston *et al.*[34] used gamma irradiation (with an irradiation cycle of 5 Gy/min for 13 hours 40 minutes, giving a dose of 4100 Gy) for the disinfection of artificial sub-surface root caries lesions. They reported that the depth of demineralization, depending on irradiation, was about 174 μm. In the pre-irradiated groups, 20% and 25% polyalkenoic acid conditioners were applied for 10 to 25 seconds on the dentin surface after irradiation. The polyacid conditioning protocol did not remove nor alter the affected dentin surface layer from irradiation. This is because dentin was demineralized by a depth of about 0.5 μm when 25% polyacrylic acid was used on intact dentin surface[19].

This study was based on *in vitro* conditions. Clinically, sound dentin is covered by enamel. However, the dentinoenamel (DEJ) junction in human teeth is not smooth but scalloped, which means that there is no tight interproximal contact at DEJ[35]. Radiation caries frequently occurs in the cervical regions and carious lesion undermines the usually demineralized enamel, suggesting an increased caries susceptibility of irradiated dentin[1]. Furthermore; stability in the region of the dentino-enamel junction reduces after radiotherapy[2]. Hecker *et al.*[36] reported that radiation therapy could cause loss of appetite, which could be caused by undiagnosed dental caries and other oral health problems. Noting that irradiated dentin is inevitably susceptible to dental caries in the oral environment, dentin surfaces were thus directly irradiated in the present study[1,9].

CONCLUSIONS

Within the limitations of this *in vitro* study, it was concluded that if irradiation were applied after a GIC is bonded to dentin, radiation may affect the chemical bonding of GIC to dentin. Conversely, if GIC is bonded to dentin after radiation is applied, the GIC-dentin bond strength will not be adversely affected.

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