EFFECTS OF IONIZING RADIATION ON MECHANICAL PROPRIETIES OF RESTORATIVE MATERIALS AND ENAMEL IN UPPER MOLARS: AN *IN-VITRO* STUDY

Perya Pelin Özsöyler Bozan[1], Ayşe Gülbin Kavak[2], Mikail Aslan[3], Hanifi Çanakçi[4], Abdullah Tuncay Demiryürek[5,6]

[1]Department of Oral and Dental Health, Vocational School of Health Services, Gaziantep University, 27310 Gaziantep, Turkey
[2]Department of Radiation Oncology, Faculty of Medicine, Gaziantep University, 27310 Gaziantep, Turkey
[3]Department of Metallurgical and Materials Engineering, Gaziantep University, 27310 Gaziantep, Turkey
[4]Department of Civil Engineering, Hasan Kalyoncu University, 27010 Gaziantep, Turkey
[5]Department of Medical Pharmacology, Faculty of Medicine, Gaziantep University, 27310 Gaziantep, Turkey
[6]Vocational School of Health Services, Gaziantep University, 27310 Gaziantep, Turkey

ABSTRACT

Introduction: Radiotherapy is one of the most commonly used treatment modalities for head and neck cancer patients, but the effects of ionizing radiation on restorative tooth materials and enamel are largely unknown.

Objectives: This study aimed to assess the effects of ionizing radiation on mechanical properties of restorative materials and enamel in upper molars.

Material and methods: A total of 60 extracted human molar teeth (40 with minor occlusal caries and 20 non-carious) were used in this study. Teeth were randomly divided into three groups, including group 1 (control group, samples received no restorative materials), group 2 (teeth were restored *in-vitro* with glass ionomer cement), and group 3 (teeth were restored *in-vitro* with flowable resin composite). Each group was divided into two sub-groups: those irradiated with a single dose of 70 Gy and those non-irradiated. Rockwell hardness tests and radiodensity measurements on Hounsfield scale were applied to the teeth before and after irradiation. A compression test was done at the end of the experiment.

Results: Radiation therapy caused significant reductions in the surface hardness in the two restorative groups ($p < 0.001$). Hounsfield units in the flowable resin composite group markedly decreased after radiation ($p < 0.001$). However, no significant effects in compressive strength were observed in any group treated with radiation.

Conclusions: These results showed that radiation has negative effects on the mechanical properties of the teeth. The surface hardness was significantly depressed by ionizing radiation. Since the radiodensity in Hounsfield scale was markedly diminished in the flowable resin composite group, glass ionomer cement could be a better alternative for cementation in teeth subjected to radiation.

Key words: cementation, compressive strength, dental enamel, hardness, radiotherapy.

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Address for correspondence: Perya Pelin Özsöyler Bozan, DMD, Oral and Dental Health, Vocational School of Health Services, Gaziantep University, 27310 Gaziantep, Turkey, phone: +90-532-6424027, e-mail: ozsoylerpelin@gmail.com

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INTRODUCTION

Head and neck cancer ranks as the seventh most common type of cancer worldwide, with an incidence rate of 13.6% [1]. Cancers of the head and neck can be treated with different modalities, including radiotherapy, surgery, chemotherapy, or a combination of these treatment approaches [2]. During ionizing radiation therapy, healthy surrounding tissues, such as teeth, mucosa, salivary glands, and bones, are all affected. One of the most serious adverse effects of radiotherapy is tooth damage. This effect can cause impairment of oral function and markedly reduce quality of life [3].

In clinical settings, radiation therapy for squamous cell carcinomas of the head and neck utilizes a total dose range from 50 to 70 Gy [4]. Ionizing radiation can cause direct destruction to hard structures of the teeth, and this damage is believed to be one of the reasons for the formation of caries in irradiated persons [5]. Impairment of salivary secretion, enhanced plaque accumulation, and caries also encourage periodontal disease development, which results in loss of teeth or premature extraction. However, the number of reports on the modification of tooth structure with radiation therapy is currently inadequate, and there is a lack of consensus in these studies [6-9]. Although some authors have indicated no variations in tooth tissues following radiation [6], other studies have shown an increase in enamel micro-hardness [8, 10].

It has been stated that there are ten times greater odds of tooth damage for radiation doses above 60 Gy. This is probably due to a decreased salivary function and alterations in the dental structure [11]. Published studies indicate that radiation can modify the properties of restorative materials [12, 13]. The effects of ionizing radiation on the structural properties of restorative materials, such as micro-hardness [14, 15], flexural strength [14, 15], surface roughness [14], diametral tensile strength, and water sorption [16], have been examined in several previous investigations. However, no published studies to date have used the Rockwell hardness test, radiodensity measurements, or compression tests of dental restorative materials, including flowable resin composite or glass ionomer cement.

OBJECTIVES

The goals of this research were to determine the effects of ionizing radiation on two restorative materials and enamel using the Rockwell hardness test, radiodensity measurements, and compression tests on molar teeth. Therefore, the null hypothesis tested was: The ionizing radiation would not affect the mechanical properties of restorative materials and enamel in upper molars.

MATERIAL AND METHODS

Sixty human molar teeth recently extracted for orthodontic reasons, both healthy and with incipient caries lesions, were collected for this study. While 40 freshly extracted teeth with minor occlusal caries were examined and collected, 20 non-carious teeth were used as a control. All non-carious teeth had a medical indication to extract due to loss of periodontal ligament support, or for orthodontic reasons. Cavity dimensions for enamel caries were not more than 2 mm × 2 mm × 1 mm. All caries were present on the occlusal surface. Teeth with developmental anomalies, attrition, abrasion, erosion, restoration, cracking, fracture, hypoplasia, or exposure to radiation were excluded from the study. Teeth with restorations and/or large cavitated lesions on the occlusal surface were also excluded.

The extracted teeth were immediately washed, immersed for 10 min in disinfectant solution (1% sodium hypochlorite), and then rinsed with running water for 3 min and kept in distilled water at 4°C until further testing [17].

The specimens were randomly divided by simple randomization using Excel into three groups (based on the time of restoration, $n = 20$ teeth for each group), and two commercially available restorative materials were investigated:

- Group 1: Control, without any restorative material.
- Group 2: Restored with glass ionomer cement (i-LINER, light curing compomer liner, Medicinos Linija, UAB, Lithuania).
- Group 3: Restored with flowable resin composite (DentLight-flow, VLADMIVA, Belgorod, Russia).

All restorations were performed on the extracted teeth by a dentist (PPÖB) in an *in-vitro* condition. After the group division, each group was separated into two sub-groups, and each group with $n = 10$ received irradiation. The Rockwell hardness tests and radiodensity measurements on the Hounsfield scale were applied to the samples before and after irradiation. A compression test was done at the end of the experiment (Figure 1).

RADIATION EXPOSURE

The teeth in each group were fixed into wax patterns, and then placed in the center of a Styrofoam container for irradiation application. The accumulated doses for both cancer and sub-mandibular gland have been reported to be 70.63 Gy [18]. There was also no marked difference between surface micro-hardness and roughness for 2 Gy/fraction/day (total, 35 days), and a single 70 Gy irradiation dose [19]. Based on these reports, all teeth in this study received a single dose of 70 Gy in one fraction. Radiation was applied to the teeth with 6 MV of photon energy using Elekta linear accelerator (Elekta Synergy Platform Linear Accelerator, Elekta Inc., Stock-

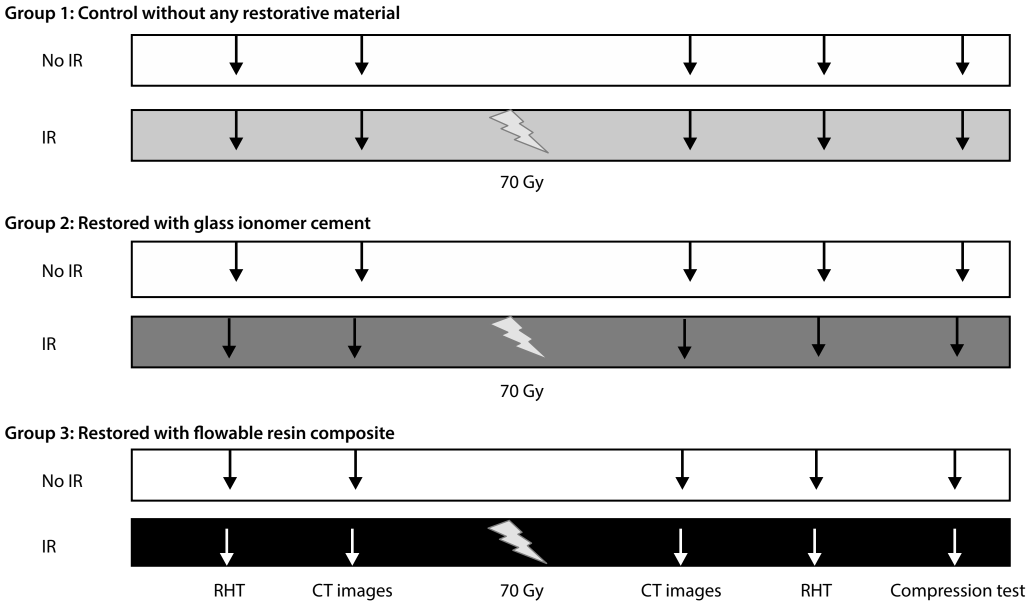

FIGURE 1. Scheme of experimental protocol for the study. All teeth in IR (irradiation) groups received one single experimental dose of 70 Gy in one fraction. RHT – Rockwell hardness test, CT – computed tomography

holm, Sweden) at the Radiation Oncology Department of Gaziantep University. The collapsed cone-dose algorithm was applied during the planning process to ensure that all teeth received the same radiation dose.

ROCKWELL HARDNESS TEST

Rockwell hardness method is defined as the macrohardness test [20]. In this study, surface hardness measurements were made for all samples with a Rockwell hardness tester machine (Matsuzawa DXT-3, Rockwell type hardness tester, Matsuzawa Seiki Co. Ltd., Tokyo, Japan). Rockwell hardness tests consisted of forcing an indenter (ball) into the surface of teeth with two loads. A 1/16 inch diameter diamond ball indenter with a load of 60 kg. force was used for testing. Three readings were obtained from the enamel for each specimen, and mean value was noted.

RADIODENSITY MEASUREMENTS WITH HOUNSFIELD SCALE

X-ray computed tomography (CT) images were recorded from the teeth using a CT scanner (Philips Brilliance 64 Slice CT, Philips Medical Systems, The Netherlands). Hounsfield scale was applied to measure radiodensity in medical CT scans.

COMPRESSION TEST

Compression test is the most commonly applied technique, which is utilized to determine the crush resistance force or compressive force of a material under different loads [21]. Since most mastication forces are compressive in nature, it is important to investigate teeth under this condition [22]. Compressive strength was tested using a universal testing machine (UTM-0108 multiplex universal electromechanical test machine, *U*-test material testing equipment, Ankara, Turkey).

STATISTICAL ANALYSIS

Values were expressed as means ± SD. SPSS software (version 22, SPSS Inc., Chicago, Illinois, USA) was used to perform the statistical analyses. Kolmogorov-Smirnov test was applied to determine if the values were normally distributed, and the values were found to have normal distributions. The repeated-measures ANOVA with post-hoc Bonferroni test was utilized to compare the means between groups. Pearson's test was used to calculate the correlation. A p-value less than 0.05 was accepted as statistically significant.

RESULTS

In total, 60 molar teeth were used in the present study, and no contamination was observed in the teeth stored in distilled water for 3 months of the experimental period.

Surface hardness measurements showed that restorations of the teeth with either flowable resin composite or glass ionomer cement markedly increased the hardness compared with controls before radiation ($p < 0.01$, Figure 2). There were marked differences in the macrohardness of surface enamel among all the groups after

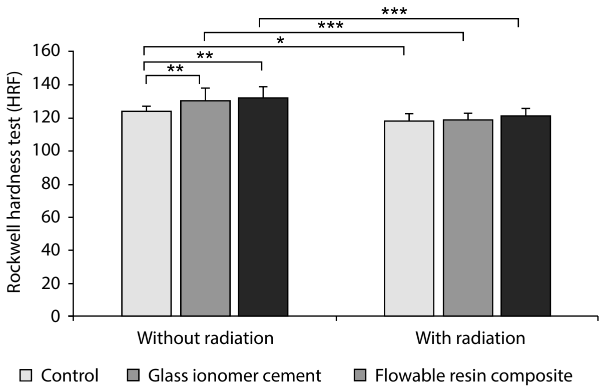

FIGURE 2. Results of surface hardness measurements. Data are presented as mean ± SD; $n = 10$ for each group; *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$

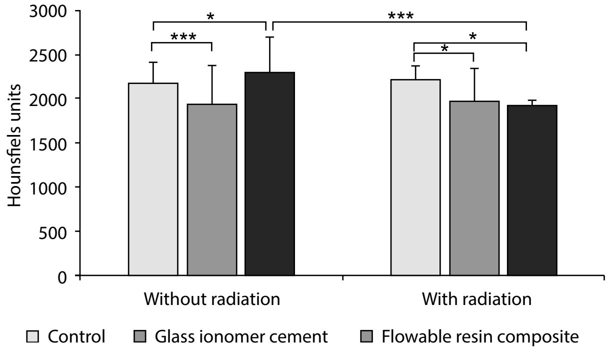

FIGURE 3. Results of X-ray computed tomography (CT) data. Values are presented as mean ± SD; $n = 10$ for each group; *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$

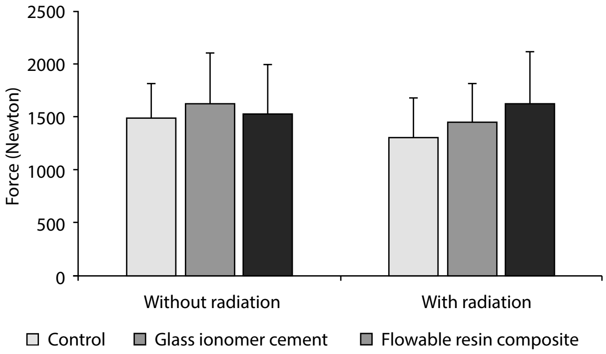

FIGURE 4. Results of compressive strength measurements. Data are presented as mean ± SD; $n = 10$ for each group

TABLE 1. Significant correlations between the groups

Parameter	Correlation coefficient (r)	Determination coefficient (r^2)	p-value
Before radiation			
Radiodensity with Hounsfield scale			
Control ↔ Flowable resin composite	0.526	0.277	0.017
Before and after radiation			
Radiodensity with Hounsfield scale			
Glass ionomer cement	0.767	0.588	0.009

irradiation. Radiation exposure caused statistically significant reductions in the surface hardness in all groups ($p < 0.05$ for control, $p < 0.001$ for restoration groups, Figure 2).

Radiodensity of the teeth showed significant variations. We found that Hounsfield items of the teeth were markedly decreased in the glass ionomer cement group, but these values were augmented in the flowable resin composite group before radiation exposure (Figure 3). Hounsfield units in the flowable resin composite group markedly declined after radiation ($p < 0.001$). There were also decreases in Hounsfield measurements in both the glass ionomer cement and flowable resin composite groups when compared with the controls after radiation exposure ($p < 0.05$ for all) (Figure 3).

There were no marked changes in the compression test between the groups. Additionally, no significant effects in the compressive strength were observed with radiation exposure (Figure 4).

Correlation analysis revealed that there was a positive correlation in radiodensity measurements with the Hounsfield scale between the control and flowable resin composite groups before radiation exposure (Table 1). A positive correlation in radiodensity measurements was also detected in the glass ionomer cement group when compared with before and after radiation groups (Table 1). No significant correlations were found with the other group comparisons.

DISCUSSION

The present study focused on the effects of ionizing radiation on the mechanical properties of upper molars. We found a marked decrease in the surface hardness in teeth with glass ionomer cement and flowable resin composite after radiation. Radiodensity was significantly reduced in the flowable resin composite, but not in the glass ionomer cement, group. Our findings are in agreement with clinical studies showing that glass ionomer cement provides better protection against caries lesions associated with restorations than composite resins in irradiated patients [23, 24].

Clinically observed common adverse effect of radiotherapy is the destruction of dental hard tissue. These negative effects of radiotherapy could be attributed to the morphological alterations observed in previous studies [8, 25, 26]. Occasionally, a brown discoloration can also be visible. The generation of atypical and recurrent patterns of dental caries in irradiated teeth is not only due to loss of salivary fluid secretion, but also a combination of both the direct effects on hard the dental structure and hypo-salivation [3]. These studies suggest that oral complications following radiation therapy for cancer are frequent and have a negative impact on the quality of life.

Since there is an increased number of patients with head and neck cancer, closely linked with raised radiotherapy requirements, it becomes more critical to learn the effects of radiation therapy on teeth, and how it can influence the restoration materials [27]. It has been demonstrated that the irradiation of teeth negatively affected the dentine bond strength though the restorations were done prior to radiotherapy [17]. We observed a marked decrease in surface macro-hardness in teeth following radiation exposure. However, there are controversial results in the published studies regarding the effect of irradiation on micro-hardness properties of dental hard tissues. Various studies have reported increases [8, 9], some have shown no changes [19, 28], and some have noted decreases [7, 21, 26, 29-31] in the overall enamel micro-hardness after radiation therapy. Both increases and decreases were also reported for micro-hardness of the permanent teeth enamel after several radiation doses (20 to 60 Gy) [10]. Muñoz *et al.* [32] also indicated that cobalt irradiation with different doses (0, 20, 40, and 70 Gy) markedly diminished micro-hardness; therefore, this is still one of the complications concerning radiotherapy and should be examined further.

Radiation can cause direct damage to hard dental structures, such as alterations in micro-hardness, elevated enamel solubility, and crystal composition. Radiation effects on dental structures are related to changes in the organic and mineral content of tooth tissues [10, 27]. It has been reported that radiation of 60 Gy caused reductions in all elements of teeth [10, 33]. Radiotherapy can induce the formation of oxidative stress with the production of hydrogen peroxide and free radicals. In the presence of water, free radicals can function as a strong oxidant that can lead to the denaturation of molecular structures [34]. There are reports of decreased enamel hardness post-radiation, which can be explained by decarboxylation of the tissue due to radiation, which can induce micro-cracks in hydroxyapatite minerals [35, 36]. Therefore, smaller crystallites are generated and the tissue surfaces become rough [35]. As a consequence of decarboxylation, the elasticity and hardness of enamel and dentine are considerably diminished. There is also a report showing that a single dose of 70 Gy of enamel increases rather than decreases its' resistance to artificial caries [37]. We observed that irradiation had no effects on the compressive strength. However, radiodensity with Hounsfield units declined in the flowable resin composite group, but not in the glass ionomer cement group after radiation, suggesting that glass ionomer cement would be more suitable for irradiated patients.

LIMITATIONS

The main limitation of this study was to use of one single 70 Gy radiation dose, which is not clinically approved and used in-vivo. However, it demonstrated the potential effect of a single high-dose on the dental structure. Additionally, previous *in-vitro* studies that have not used fractionated doses are also present [37, 38].

CONCLUSIONS

Our *in-vitro* study showed that directly exposed radiation causes potential harm on the hard tissues of the tooth. Since the radiodensity properties of the teeth are enormously decreased with irradiation in teeth restored with flowable composite resin, glass ionomer cement could be a better alternative for cementation in teeth subjected to radiation. Dentists should be aware of the damaging effects of radiation, and be cautious when selecting restorative material for irradiated patients.

CONFLICT OF INTEREST

The authors declare no potential conflict of interests with respect to the authorship and/or publication of this article.

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