ORIGINAL RESEARCH

Effect of Ionizing Radiation on the Mechanical Properties of Two Dental Materials Commonly Used in Primary Teeth

Basma M Nagi[1], Dalia I El-Korashy[2], Amin El-S Amin[3], Amr M Abdelaziz[4], Reham K Elghazawy[5]

Abstract

Aim: The purpose of this *in vitro* study was to evaluate the effect of radiotherapy on flexural strength, microhardness, and surface roughness of bulk fill composite (X-tra fil) and glass ionomer (EQUIA Forte HT).

Materials and methods: A total of 40 specimens were prepared for each test and were divided into two groups according to the material used (composite or glass ionomer cement), and each group was divided into two subgroups (n = 10) according to radiation condition, irradiated subgroup, subjected to 50 Gy by multienergy linear accelerator delivered in one shot and control subgroup.

Results: Control samples of flexural strength and microhardness had a significantly higher value than irradiated samples in both materials. Regarding the surface roughness, irradiated samples had a significantly higher value than the control samples in both materials.

Conclusion: Irradiation with a linear accelerator had a negative impact on the flexural strength and microhardness of both materials. Moreover, it increased the surface roughness for both materials. Bulk fill composite is the dental restorative material of choice in head and neck cancer patients undergoing radiotherapy due to its high mechanical properties before and after radiation.

Keywords: Bulk fill composite, Glass ionomer, Ionizing radiation, Radiotherapy.

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Introduction

Many pediatric head and neck cancers now have significantly higher survival rates when radiation therapy (RT) is combined with surgery or chemotherapy. However, RT can result in unfavorable effects that emerge while or after the treatment for head and neck malignancies.[1] Changes in the oral mucosa, skin, salivary glands, bones, and teeth can result in problems such as dehydration, malnutrition, and systemic infections. The incidence and severity of these complications can be avoided or at least reduced by implementing oral care guidelines before RT and routine examination of lesions during therapy.[2]

Prior to RT, infectious lesions in the oral cavity must be removed or at least reduced, which includes treating dental caries.[3,4] Radiation-related caries are a very frequent adverse reaction to RT as a result of changes in oral microorganisms, difficulties in maintaining good oral hygiene, adoption of a soft diet due to difficulty in swallowing, and changes in flow rate and quality of saliva.[5] Tooth restoration should be used to treat radiation caries since it can also develop because of changes in the crystalline structure, enamel and dentin microhardness, dentin enamel junction, and acid solubility of enamel.[6,7]

The radiation dosage distribution is unaffected by tooth-colored restorative materials, in contrast to metallic restoration. However, they might experience structural and compositional alterations as a result of RT, which would change their mechanical and physical characteristics.[8]

Mechanical properties such as flexural strength, surface roughness, and microhardness are important due to their influence on the clinical performance and durability of esthetic restorations.[9] Accordingly, this study was formulated to evaluate the effects of irradiation on the mechanical properties of a bulk-fill composite resin and a highly viscous glass ionomer cement restorative material and allow the dentists to select the best materials in these situations. The hypothesis was that ionizing irradiation had no effects on the mechanical behavior of these materials used in restorative procedures.

[1,4,5]Department of Pediatric Dentistry and Dental Public Health, Faculty of Dentistry, Ain Shams University, Cairo, Egypt

[2]Department of Biomaterials, Faculty of Dentistry, Ain Shams University, Cairo, Egypt

[3]Department of Radiation Oncology and Nuclear Medicine, Faculty of Medicine, Ain Shams University, Cairo, Egypt

Corresponding Author: Basma M Nagi, Department of Pediatric Dentistry and Dental Public Health, Faculty of the Dentistry, Ain Shams University, Cairo, Egypt, Phone: +2001026155509, e-mail: basmamahmoud@dent.asu.edu.eg

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Materials and Methods

Sample Size Calculation

A power analysis was created to have sufficient power to do a statistical test of the null hypothesis, which states that there is no difference between the different tested groups. Based on the results of previous studies[10–12] and by adopting an α-level of 0.05 and a β of 0.2, that is, power = 80%, the calculated sample sizes were:

- Flexural strength, microhardness, and surface roughness tests: (effect size = 0.551) (n = 40) (n = 10 for each group).

- Calculations of sample size were made utilizing G*Power version 3.1.9.7.

Materials

Table 1 lists the restorative materials utilized in the study, their composition, and their manufacturers.

Specimens' Preparation

The specimens with various dimensions were prepared using split stainless-steel molds in accordance with the respective test as follows:

- Flexural strength test: 12 mm in length, 2 mm in width, and 2 mm in thickness.
- Microhardness test: 4 mm in diameter × 2 mm in thickness.
- Surface roughness test: 4 mm in diameter × 2 mm in thickness.

Composite Specimens

A glass slide was covered with a celluloid matrix, and then the mold was put on top of that. Afterward, the substance was compressed, covered with a celluloid matrix, and another glass slide. The glass slide was removed, and the center of each specimen was cured first for 10 seconds, then from each end of the mold for another 10 seconds each, with a total curing time of 30 seconds for flexural strength testing. A light emitting diode light cure (3M ESPE, Elipar, Deep cure-L, Germany) with a 1200 mW/cm^2 output was used for 10 seconds to cure for microhardness and surface roughness specimens. Every five curing sessions, the output was tested using a radiometer (model 100 curing radiometer, Kerr, United States of America). After the mold was disassembled, samples were kept in distilled water for 24 hours in an incubator at 37°C[13] before being exposed to radiation and testing.

Glass Ionomer Specimens

The mold was packed with glass ionomer (after mixing in an amalgamator for 10 seconds), which was positioned on a piece of the polyester strip over a glass slide using a flat-surfaced condenser. The material was covered with another polyester strip and gently pressed using another glass slide to extrude the excess material.[14]

The specimens were left in the mold for 1 hour and then were removed from the mold. Each specimen was checked for its length, width, and thickness using a digital micrometer, and each reading was recorded. Equia coat was applied to all surfaces of each specimen and cured for 20 seconds. The specimens were kept in distilled water at 37°C[13] in an incubator for 24 hours before testing.

The specimens of both materials were randomly divided into two subgroups (n = 10): irradiated (50 Gy) and control (0 Gy).

Table 1: Materials used in this study

Material	*Composition*	*Manufacturer*
X-tra fil composite (bulk fill resin composite)	Matrix: dimethacrylate (Bis-GMA, TEGDMA, UDMA) Filler: inorganic filler (barium aluminum silicate, fumed silica, pigments)	VOCO Cuxhaven, Germany
EQUIA Forte HT (glass hybrid restorative)	Fluoroaluminosilicate glass, polyacrylic acid powder, surface-treated glass	GC corporation Tokyo, Japan
Equia Forte coat (nanofilled resin)	Methyl methacrylate, colloidal silica, camphorquinone, urethane methacrylate, phosphoric ester monomer	GC corporation Tokyo, Japan

Bis-GMA, bisphenol A glycidyl methacrylate; TEGDMA, triethyleneglycol dimethacrylate; UDMA, urethane dimethacrylate

Mechanical Tests

Flexural Strength

The universal testing machine operated using Nexygen software version 4.6 at a crosshead speed of 0.5 mm/minute was used to conduct the three-point bending test on the specimens. Each specimen's center was subjected to the load up to fracture through a load applicator ending with a third rod (2 mm in diameter). Each specimen's maximum fracture load (Newton) was noted, and the flexural strength, measured in MPa, was determined using the following equation[12]:

$$= 3FL/(2BH^2)$$

Where:

L: distance between the supports (10 mm).

B: specimen width (~2 mm).

H: specimen height (~2 mm).

Microhardness

Specimens were retrieved from distilled water and blotted dry. Specimens were tested for microhardness using the Nexus 4000 TM Vicker's Microhardness tester (INNOVATEST Europe, BV, Borgharenweg, Netherlands). Specimens were stabilized on the machine platform, where each specimen was held perpendicular to the pyramidal indenter. Three measurements were taken for each specimen from the top surface, with a specific load of 500 gm, a dwell time of 15 seconds, and a magnification power of 20×. The mean of the three measurements was calculated.

Surface Roughness

Specimens were retrieved from the water and blotted dry. A stereomicroscope (SZ-PT, Olympus, DP10, Japan) at the Oral Pathology Department, Faculty of Dentistry, Ain Shams University, was used to evaluate the surface roughness of each specimen under a magnification of 25× using Image J software for analysis.

Application of Ionizing Radiation

Specimens were irradiated at the Department of Radiation Oncology and Nuclear Medicine, Faculty of Medicine, Ain Shams University. The specimens were placed on a solid tissue equivalent phantom with 15 cm height to allow full side and back radiation scattering. During irradiation, the specimens were covered with tissue-equivalent bolus (tissue-equivalent rubber) to build up the radiation dose. Irradiation was performed using 6 MeV X-rays produced by a multienergy linear accelerator (Precise, Elekta, United Kingdom). A radiation dose of 50 Gy was delivered in one shot.[15,16]

Statistical Analysis

Shapiro–Wilk and Leven's tests were used to examine the normality and variance homogeneity of numerical data. Data were presented as mean and standard deviation (SD) values and analyzed using a two-way model analysis of variance, followed by simple main effects comparison using multiple student t-tests with Bonferroni correction as data revealed parametric distribution and homogeneity of variances across groups. For all tests, the significance level was set at $p \leq 0.05$. R statistical analysis software for Windows, version 4.0.3, was used to conduct the statistical analysis.[17]

Table 2: Mean ± SD of flexural strength (MPa) for different groups

	Flexural strength (MPa) (mean ± SD)		
Group	*GI*	*Composite*	*p-value*
Control	36.87 ± 4.91	166.40 ± 30.29	**<0.001***
Irradiated	24.28 ± 6.90	100.25 ± 15.31	**<0.001***
p-value	**<0.001***	**<0.001***	

*Significant ($p \leq 0.05$)

Table 3: Mean ± SD of microhardness for different groups

	Microhardness (mean ± SD)		
Group	*GI*	*Composite*	*p-value*
Control	59.94 ± 2.50	72.74 ± 1.34	**<0.001***
Irradiated	52.53 ± 0.92	59.44 ± 2.50	**<0.001***
p-value	**<0.001***	**<0.001***	

*Significant ($p \leq 0.05$)

Table 4: Mean ± SD of surface roughness for different groups

	Surface roughness (mean ± SD)		
Group	*GI*	*Composite*	*p-value*
Control	165.48 ± 3.53	149.87 ± 6.63	**<0.001***
Irradiated	195.75 ± 15.62	170.75 ± 24.25	**0.019***
p-value	**<0.001***	**0.034***	

*Significant ($p \leq 0.05$)

Results

Flexural Strength (MPa)

In Table 2, the flexural strength (MPa) mean and SD values for the various groups were presented. In the control group, composite samples (166.40 ± 30.29) were significantly higher than gastrointestinal (GI) samples (36.87 ± 4.91) ($p < 0.001$), and in the irradiated group, composite samples (100.25 ± 15.31) were significantly higher than GI samples (24.28 ± 6.90) ($p < 0.001$). The irradiation factor had a significant effect on both materials. Control samples of GI (36.87 ± 4.91) were significantly higher than irradiated samples (24.28 ± 6.90) ($p < 0.001$). Control samples of composite (166.40 ± 30.29) were significantly higher than irradiated samples (100.25 ± 15.31) ($p < 0.001$).

Microhardness

Mean and SD values of microhardness for all groups are shown in Table 3. In the control group, composite samples (72.74 ± 1.34) were significantly higher than GI samples (59.94 ± 2.50) ($p < 0.001$), and in the irradiated group, composite samples (59.44 ± 2.50) were significantly higher than GI samples (52.53 ± 0.92) ($p < 0.001$). The irradiation factor had a significant effect on both materials. Control samples of GI (59.94 ± 2.50) were significantly higher than irradiated samples (52.53 ± 0.92) ($p < 0.001$). Control samples of composite (72.74 ± 1.34) were significantly higher than irradiated samples (59.44 ± 2.50) ($p < 0.001$).

Surface Roughness

Surface roughness mean and SD values for all groups are shown in Table 4. In the control group, GI samples (165.48 ± 3.53) were significantly higher than composite samples (149.87 ± 6.63) ($p < 0.001$) and in the irradiated group, GI samples (195.75 ± 15.62) were significantly higher than composite samples (170.75 ± 24.25) ($p = 0.019$). The irradiation factor had a significant effect on both materials. Irradiation of GI (195.75 ± 15.62) was significantly higher than the control samples (165.48 ± 3.53) ($p < 0.001$). Irradiated samples of composite (170.75 ± 24.25) were significantly higher than the control samples (149.87 ± 6.63) ($p = 0.034$).

Discussion

The restorative materials used in this study were chosen owing to their ability to be placed in bulk, thus accelerating the filling procedure, which is specifically crucial when dealing with children, especially patients. To stimulate the effects of irradiation, the X-rays were produced by a linear accelerator, a machine that's used in radiotherapy on a clinical level.

Flexural strength testing was chosen since it has a direct clinical correlation with the success of a material in practice.[18] The three-point bending test is still the method of choice for assessing flexural strength due to the reduced SD and coefficient of variation, despite some research suggesting other designs.[12] In addition, it exhibits less complex crack distribution.[12,19] However, the specimen dimensions, especially the specimen's length, recommended by International Organization for Standardization (ISO) were not clinically realistic; in addition to material wastage and time-consuming specimen fabrication,[10] mini-flexural specimens were used to overcome the drawbacks of the specimen's length, as recommended by ISO.[20]

Regarding the results of the flexural strength, there was a statistically significant decrease in the flexural strength for both materials after radiotherapy. This could be attributed to extensive cross-linking of the polymer of X-tra fil, making it more brittle or due to chain scission, breaking of carbon–carbon bonds of polymer chains by high radiation energy, and subsequently decreasing in the molecular weight and the flexural strength. However, this decrease

in flexural strength does not contraindicate the use of X-tra fil as the minimum requirement of ISO 4049 for occlusal restorations of resin-based materials is 80 MPa.[14] Regarding EQUIA Forte HT, the decrease in flexural strength may be attributed to microcracks as a result of dehydration caused by ionizing radiation.

The results obtained in this study were consistent with Novais et al.,[21] who reported a decrease in flexural strength after irradiation despite different materials being used. As opposed to that, these results came in contrast with Ugurlu et al.,[14] who noted an increase in flexural strength after irradiation. This inconsistency in results might be attributed to the difference in storage period between both studies and the difference in irradiation dose and source.

A surface microhardness test was selected to correlate the laboratory findings with the behavior of the material intraorally with respect to its ability to maintain its anatomical form and, accordingly, its resistance to wear. Surface microhardness results revealed a statistically significant decrease in microhardness for both materials after radiotherapy. Chemical properties could explain the reduction in microhardness of the X-tra fil composite. The chemical changes in the molecular structure of irradiated materials are affecting the macroscopic properties of resin-based materials.[22] Another potential explanation is the fact that the polymerization process in irradiated composites could be influenced by the ionizing action of radiation, which likely causes polymeric chains to rupture.[23,24] Reichmanis et al.[24] stated that high-intensity radiation excites and ionizes polymers, producing ions and free radicals, resulting in small molecules that are able to produce changes in physical and mechanical properties concurrent with polymer degradation. On the other hand, the reduction in microhardness in EQUIA Forte HT might be attributed to the fact that radiation interacts with organic and/or inorganic glass ionomer components.

The results of this study are consistent with Viero et al.,[11] who reported a decrease in microhardness after irradiation despite using different materials. As opposed to that, these results came in contrast with Lima et al.,[25] who reported no alteration in the microhardness values before and after application of ionizing radiation. This may be explained by a different radiation source (Co source and linear accelerator) and the dose used.

Surface roughness test was tested in this study since the physical and chemical characteristics of dental filling materials are considered indicators that predict their clinical efficacy. For example, the roughening of the surface of the restorative material caused by wear or chemical degradation might have an adverse effect on the surface gloss, which would increase plaque retention, shorten the restoration's durability, and may increase the chances of secondary caries.[26]

Both tested materials exhibited a significant increase in surface roughness after radiotherapy. Regarding X-tra fil, this could be explained by the effect of ionizing radiation that may promote the degradation phenomenon and increase the surface roughness in restorations applied before radiotherapy. Regarding EQUIA Forte HT, this could be attributed to how ionizing radiation interacts with the structure of water-based cement, forming oxygen-reactive materials.[25]

These results were consistent with Lima et al.,[25] who reported an increase in surface roughness after ionizing radiation. As opposed to that, these results came in contrast with Viero et al.,[11] who reported no change in the surface roughness values before and after the application of ionizing radiation. This may be explained by a different radiation source (cobalt source and linear accelerator), dose, and materials used.

The literature reports contradictory results regarding alterations in the properties of dental materials after applications of ionizing radiation.[9,14,27,28] The variations in material composition might provide an explanation for this fact (fillers, matrix, and initiator systems), the difference in intensity of the light cure unit, storage periods, different radiation sources (cobalt source and linear accelerator) as well as the dose used. All of these variables may cause polymer chains to cross-link, increasing their molecular weight, or they may scission, decreasing their molecular weight, affecting the characteristics of polymeric materials significantly.[29]

Furthermore, it is important to highlight that the behavior of the materials may change when used in the oral environment. There are a variety of agents that affect the oral cavity in a more sophisticated way than the experimental ones employed in this study.

Conclusions

Irradiation with linear accelerators had a negative impact on flexural strength, microhardness, and surface roughness for both materials.

- Overall, X-tra fil presented a better performance in irradiated teeth compared to EQUIA Forte HT.
- The clinical trial is highly required regarding the effect of radiotherapy on restorative materials.

Orcid

Basma M Nagi https://orcid.org/0000-0001-8649-1741
Dalia I El-Korashy https://orcid.org/0000-0002-2476-4131
Reham K Elghazawy https://orcid.org/0000-0001-5433-2631

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