Effect of irradiation on the mechanical behavior of restorative materials

Efeito da radioterapia no comportamento mecânico de materiais restauradores

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ABSTRACT

Purpose: This study evaluated the influence of cobalt-60 gamma irradiation on mechanical properties of restorative materials. Material and Methods: Two glass ionomer cement (Ketac Molar and RelyX Luting), a composite resin (Filtek Z350) and two feldspathic ceramics (VITA VMK-95 and StarLight) were evaluated. The samples were made in accordance with the ISO normative for the four-point bending test (n = 20), diametral tensile (n = 20) and microhardness tests; Knoop hardness (KHN) for glass ionomer and composite, and Vickers hardness (VHN) for ceramics (n = 10). The samples were divided into two groups: irradiated (Ir), subjected to cobalt-60 gamma irradiation in a similar protocol used for patients with head and neck tumor; and control group (C), samples not subjected to the irradiation protocol. Results: Data were analyzed using one-way ANOVA, for diametral tensile and four-point bending test, and two-way ANOVA followed by the Tukey's HSD test (α=.05), for Knoop and Vickers microhardness. Gamma irradiation significantly reduced the diametral tensile strength only for Ketac Molar (P<.001). Composite resin presented flexural strength values significantly decreased when submitted to the radiotherapy (P<.003). For all materials tested, the microhardness was not influenced by the region (top and bottom). Irradiation increased the KHN values for Ketac Molar (P<.000) and decreased for the RelyX Luting 2 (P<.002). The VHN was not influenced by the irradiation. Conclusions: Gamma irradiation therapy influenced the mechanical properties of the glass ionomers and the composite resin, although not alters any ceramic properties.

KEYWORDS: Dental materials, Radiotherapy, Biomechanics.

INTRODUCTION

Radiotherapy is a well-established method, which is indicated for treatment of malignant tumors because it destroys cancer cells while preserving normal cells[1] and has been the main choice for treatment of patients[2]. However, ionizing irradiation has numerous adverse reactions that significantly affect the patient's quality of life and may even affect the progress of treatment[3]. This damage is particularly evident in the head and neck region where a variety of structures with high radiosensitivity is found[4].

Reports in the literature show indirect damage to tooth structures caused by irradiation, including a high incidence of coronal tooth destruction, mainly due to irradiation caries[5] and pulp changes arising from changes in mandibular lymphatic circulation flow[6]. The deleterious effects of irradiation on dental tissues occur particularly at the dentin-enamel junction[5]. Moreover, direct damage from irradiation such as structural changes of the crystalline portion and in the organic portion of dental mineralized tissues have also been reported[1]. Changes in the oral environment[7], drop in pH, and hygienic difficulties induced by xerostomia make the oral environment highly cariogenic[8], highlighting the need for high performance and stability of the restorative materials that are used in these cases[5].

The restorative procedure of patients who have undergone head and neck radiotherapy can be extremely stressful for patients and clinicians[3,9]. Ionizing irradiation in contact with restorative materials of high atomic density such as the amalgam and alloys may aggravate the damage to dental tissues and soft tissues[2,10]. In addition, another concern is the performance of adhesives procedures in irradiated dentin. Some studies have been conducted to evaluate the efficiency of adhesion in direct restored irradiated dentin, especially after high-dose irradiation[11,12]. However, restorations using different materials that can be integrated through adhesion to the tooth structure tend to be the best methods to restore pre- or post-irradiated teeth[11] despite showing different results[12,13].

To determine the best alternative for oral rehabilitation of patients undergoing radiotherapy treatment is essential[8,14]. In this context, the assessment of the mechanical properties of different dental materials that may be affected by radiotherapy could allow the clinicians to choose the best materials in these situations. Therefore, the aim of this study was to evaluate the effects of irradiation on the mechanical properties of glass ionomer cements, composite resins and feldspathic ceramics by mechanical testing of four-point flexural strength, diametral tensile strength and microhardness. The hypothesis was that ionizing irradiation affects the mechanical behavior of these materials used in restorative procedures.

MATERIALS AND METHODS

Five materials were selected for evaluation in this study (Table 1). The samples were prepared according to the protocol established by the International Standardization Organization (ISO) for the four-point bending test (n = 10), diametral tensile test (n = 10) and for the Knoop hardness (KHN) and Vickers hardness test (n = 10) (Figure 1). The four-point bending test was not performed for the ionomer materials because of the shape distortion suffered by these materials during the preparation.

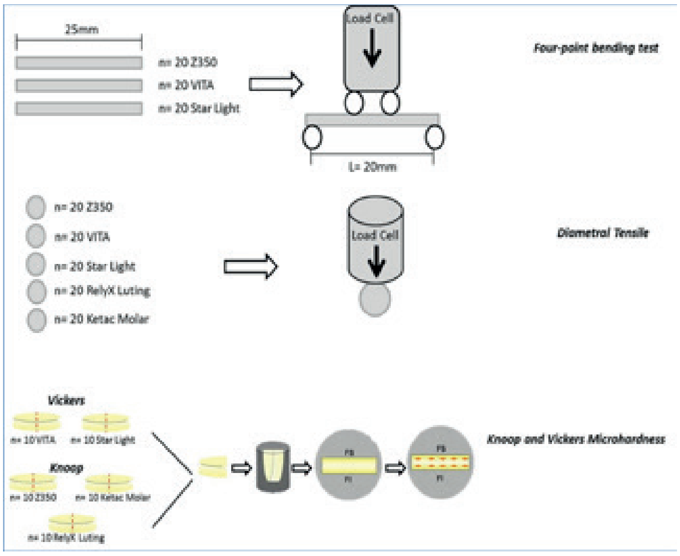

Figure 1 - Experimental groups and scheme of each test.

Table 1 - Product, composition and manufacturer of the materials evaluated in the study

Type of Material	Product	Composition	Manufacturer
Conventional Glass Ionomer	Ketac Molar	Powder: glass fluorsilicate, strontium and lanthanum Liquid: Acid bonico polycar-bonates, tartaric acid and water.	3M-Espe, St. Paul, MN, USA
Ionomer Cement	RelyX Luting 2	Folder A: Fluoroaluminosilicato (FAS) vitreo, redu-cing agent itself, HEMA, water,opacifier agent. Folder B: Acid Methacryla-te polycarboxylic BisGMA, HEMA, Water, Po-tassiumPersulfate, Zirconia--silica particle.	3M-Espe, St. Paul, MN, USA
Composite Resin	Filtek Z350	Filler, bisphenol A polyethylene glycol dimethacrylate dieter, diuretano, bisphenol Adiglyci-dyl ether dimethacrylate, triethylene-glycol and pigment.	3M-Espe, St. Paul, MN, USA
Feldspathic porcelain	VITA VMK-95	Kalium natural - (KAlSi3O8); Orthoklas e feldspatos de sódio e/ou potássio (NaAlSi3O; Albit)	Vita Zahn-fabrik, Bad Sackingen, Germany
Feldspathic porcelain	Star Light	Powder: Metal Oxide and Pig-ments Liquid: Water, Alcohol and Pro-prileno-Glicol	Dentsply, Hanau--wolfgang Germany

Preparation of specimens for mechanical tests

For the four-point bending test, rectangular specimens (2.0 mm X 2.0 mm X 25.0 mm) were prepared using a stainless steel mold according to ISO4049 as follows: the composite resin (Z350, 3M ESPE, St. Paul, Minnesota, USA) was placed in increments of 2.0 mm inside the molds and light cured for 20 seconds with a halogen unit (XL3000, 3M-ESPE, St. Paul, Minnesota, USA) at 800 mW/cm^2. The two types of feldspathic ceramics were also fabricated according to the manufacturers' instructions, following the specific dimensions of the molds. For the diametral tensile test, the specimens were prepared according to the specifications of ADA nº 27, using a bipartite aluminum mold with a diameter of 6.0 mm and a thickness of 3.0 mm. The materials RelyX Luting and Ketac Molar (3M ESPE, St. Paul, Minnesota, USA) were manipulated according to the manufacturers' instructions and inserted into the molds. KHN and VHN test samples were prepared in the shape of half-circles with a thickness of 3.0 mm and diameter of 6.0 mm. Finishing and polishing procedures were carried out using # 600, 800, 1200 and 1500 silicon carbide sandpaper (Norton, Campinas, Sao Paulo, Brazil), and felt discs associated with diamond paste of granulometry of 6, 3, 1 and ¼ (Aerotec, Sao Paulo, SP, Brazil).

The samples of the irradiated groups were subjected to a radiotherapy protocol with 60 Gy of cobalt-60 gamma irradiation fractionated into 2 Gy daily, 5 days per week. This protocol is the same as the one used in patients under oncogenic treatment for head and neck tumors and was applied in a specialized cancer center (Uberlandia Cancer Hospital, Federal University of Uberlandia, MG, Brazil) with a Co-60 teletherapy unit (Theratron Phoenix 60Cobalt Radiotherapy Treatment Unit - Theratronics International, Ltd., Atomic Energy of Canada, Ltd., AECL Medical, Ottawa, ON, Canada). The samples were stored in distilled water that was changed weekly during the irradiation procedure. The samples from the control group were stored in distilled water until performing of the mechanical tests.

Mechanical Tests

Four-point bending test

The four-point bending test was performed with two application tips with diameters of 2.0 mm. The specimens were centrally positioned on 20 mm span distance between lower supports adapted to a mechanical testing machine (EMIC 2000 DL, Sao Jose dos Pinhais, PR, Brazil), and the load was applied at a speed of 0.5 mm/min until fracture. The flexural strength (σ), which was measured in MPa, was calculated using the following formula[15]: [$\sigma = PL/wb^2$], where P is the maximum load (N), L the distance between the lower supports (20.0 mm), w the width (2.0 mm) and b the height of the specimen (2.0 mm) (Fig 1).

Diametral Tensile test

The samples were tested in a mechanical testing machine (EMIC 2000 DL, Sao Jose dos Pinhais, PR, Brazil) using a compressive load in the diametrical surface of the samples with a speed of 0.5 mm/min. The diametral tensile strength (DTS) was calculated using the following formula[15]: [$DTS = 2P/\pi DT$], where P is the maximum load when the breakdown occurred, D the diameter of the sample and T the thickness of the sample.

Knoop (KHN) and Vickers (VHN) Microhardness

The KHN was determined with microindenter FM-700 (Filter-Tech Corp., Tokyo, Japan) with a load of 50 g for 30 seconds. Five indentations at the bottom and top were made in each specimen. For ceramic materials, the VHN was determined by applying a load of 200 g for 15 s[16,17].

Statistical analysis

One-way ANOVA was performed considering the irradiation factor for four-point bending test and diametral tensile. Two-way ANOVA (2 x 2) was used for the Knoop and Vickers microhardness, considering the factor irradiation and region analyzed (top and bottom) followed by Tukey's HSD test (α=.05).

RESULTS

Flexural strength means for the four-point bending test are shown in Table 2. One-way ANOVA revealed that irradiation was only a significant factor for composite resin (*P*<.003) resulting in a significant reduction in its flexural strength. Diametral tensile strength (DTS) values are presented in Table 3. One-way ANOVA showed that the irradiation factor was only significant for the Ketac Molar (*P*<.001), which had decreased DTS values after irradiation. The KHN means are shown in Table 4. Two-way ANOVA showed no significant differences between the regions analyzed (top and bottom) for all tested materials. The gamma irradiation factor was significant for Ketac Molar (*P*<.000) and for the RelyX Luting (*P*<.002). Ketac Molar showed an increase in KHN values, while the RelyXLuting 2 showed decreasing KHN values. The VHN means are shown in Table 5. Two-way ANOVA revealed no effects of the gamma irradiation factor and the region (top and bottom) for both ceramics tested.

Table 2 - Mean values (MPa) and standard deviation of flexural strength for irradiation factor

Material	Unirradiated	Irradiated
Filtek Z350	55.4 (12.5)a	31.7 (12.8)b
Vita VMK 95	35.1 (8.8)a	34.64 (7.9)a
StarLight	34.0 (10.1)a	37.80 (8.2)a

* Different letters mean statistically significant difference in the horizontal (P<0.05).

Table 3 - Mean values (MPa) and standard deviation of diametral tensile strength for irradiation factor

Material	Unirradiated	Irradiated
Ketac Molar	6.9 (1.7)a	3.7 (2.4)b
Rely X Luting 2	12.2 (4.2)a	11.4 (3.1)a
Filtek Z350	23.0 (4.0)a	21.6 (3.3)a
Vita VMK 95	35.1 (7.4)a	24.9 (15.3)a
StarLight	33.3n (15.6)a	29.3 (10.1)a

* Different letters mean statistically significant difference in the horizontal (p<0.05)

Table 4 - Mean values (MPa) and standard deviation of Knoop Microhardness (HKN) for irradiation factor and top and bottom regions of the tested materials

	Material					
	Ketac Molar		Rely X Luting 2		Filtek Z350	
	Top	Bottom	Top	Bottom	Top	Bottom
Unirradiated	32.9 (4.8)Ab	34.3 (5.5)Ab	25.8 (1.8)Aa	25.9 (5.6)Aa	65.9 (11.2)Aa	62.4 (3.5)Aa
Irradiated	54.3 (3.2)Aa	55.3 (5.0)Aa	20.8 (2.0)Ab	19.4 (3.0)Ab	67.6 (5.8)Aa	73.6 (6.0)Aa

* Different lowercase letters mean significant differences in the vertical (irradiation factor) (P<0.05). Different uppercase letters mean significant differences in the horizontal (top and bottom regions) for the same material (P<0.05).

Table 5 - Mean values (MPa) and standard deviation of Vickers Microhardness (HKN) for irradiation factor and top and bottom regions of the tested materials

	Material			
	Vita VMK 95		StarLight	
	Top	Bottom	Top	Bottom
Unirradiated	10.5 (0.4)Aa	10.2 (0.4)Aa	10.5 (0.4)Aa	10.2 (0.4)Aa
Irradiated	9.8 (0.8)Aa	10.5 (0.4)Aa	10.8 (0.5)Aa	10.5 (0.4)Aa

*Different lowercase letters mean significant differences in the vertical (irradiation factor) (P<0.05). Different uppercase letters mean significant differences in the horizontal (top and bottom regions) for the same material (P<0.05).

DISCUSSION

The tested hypothesis was confirmed. Irradiation modified the mechanical properties of composite resin and glass ionomer cements. Some studies have been conducted to determine the effect of irradiation on the mechanical properties of restorative materials[3]. However, these studies used relatively low dosages, up to a maximum of 10 Gy, compared to the standard protocol-average of the usual dose of 60 Gy, which is used for treatment of head and neck cancers[1,14]. Therefore, to simulate the effects of irradiation on restorative materials, we followed the radiotherapy protocol performed clinically in patients undergoing radiotherapy at the Cancer Hospital of the Federal University of Uberlandia. During irradiation, the samples were immersed in distilled water so that they could reproduce the condition of moisture present in the oral cavity. Such care was taken to ensure greater simulation of oral conditions to provide greater reliability of the results.

The occurrence of irradiation caries leads to a significant loss of tooth structure resulting in the need for restorative procedures. Some authors have proposed the use of glass ionomer cement to restore areas of higher incidence of irradiation caries[5]. The present study evaluated two types of glass ionomer cements, a conventional glass ionomer (Ketac Molar) and resin--modified glass ionomer cement (RelyX Luting 2). The results showed that glass ionomer, irrespective of the composition, was the material that developed more alterations in mechanical properties after irradiation. However, the materials behaved differently. There was an increase in microhardness for Ketac Molar, and a decrease in the compressive strength of both glass ionomer cements studied. The hardness is a property used to predict the wear resistance of a material and its ability to wear opposing dental structures[15]. Thus, the microhardness increased is a positive factor for Ketac Molar, since the irradiation has improved this property, making it more resistant. This may mean an increase in longevity of restorations made with this material. Although for Rely X Luting it has not happen, it was seen that in some way radiation interacts with organic and / or inorganic materials components, although how this occurs has not been studied element of this work.

Another material evaluated in this study was a composite resin. The clinical performance of composite resin restorations in irradiated patients is satisfactory once good marginal adaptation is present[18]. The biggest concern with the use of resin to rehabilitate irradiated patients was related to decreased adhesion strength of the material to dentin and enamel irradiated[13]. It was proven that the bond strength between composite and enamel and dentin irradiated is affected to a higher degree when the restoration is performed after irradiation, when the radiation source was Cobalt 60[13]. And other work has shown that when used IMRT radiation, there was no change in the bond strength of direct restorations with dentin irradiated[12].

This study showed some decrease of the flexural strength of composite resin after the irradiation protocol. This mechanical property is essentially measured by simultaneous interaction of tensile, compressive and shear when a compressive load is applied in the center of the specimen[15]. According to the methodologies used in this work, it becomes difficult to explain how the Cobalt 60 gamma irradiation altered the properties of the composite. But the decrease of flexural strength can be said that there was a significant change. But that does not contraindicate the use of this material. The dentist has to think not only in the adhesion or the mechanical properties of the material, but should consider the needs of the patient in decision making to restore before or after radiotherapy. More information, especially studies evaluating changes in the chemical composition and with different composites resins are required to strengthen such date.

With respect to dental ceramics, the results showed that irradiation did not alter the mechanical properties of the ceramics tested. Although the ceramic material did not show changes in its properties, its use requires a significant amount of preparation, which necessitates more wear of the tooth structure that is also fragile and has changes in its mechanical properties[19,20,21]. The changes in irradiated tooth structure may also contribute significantly to the poor performance of the restorative material[11,20]. Moreover, ceramic indirect restorations require the use of a cementing agent, and this study did not evaluate the effects of irradiation on cements indicated for this clinical situation. In addition, poor mechanical performance of the material could compromise the results and longevity of these restorations.

It is important to emphasize that cobalt-60 gamma irradiation predisposes the material to microstructural changes[19,22,23.] The most appropriate restorative procedure should be carefully chosen, taking into account changes in the mechanical properties and the requirement of this material for good clinical performance. There is no ideal material, and the fact that irradiation changes the properties of some of the materials does not contraindicate their use. It is important to the surgeon-dentist to seek the material most suited to the clinical situation of the patient. Early or late radiotherapy sequel persist for years, and the dentist should be aware about this situation[24].

The present study showed that the radiotherapy protocol affects the mechanical properties of the glass ionomers studied, only the flexural strength of composite resin and had no effects on the properties of ceramics materials. The conventional glass ionomer cement (Ketac Molar) was the material that best behaved mechanically after irradiation, since there was an improvement in the microhardness property.

The findings of this study are of paramount importance; however, additional research, especially to evaluating the chemical changes to help understand the mechanical behavior of materials, as well as clinical studies are required. The behavior of these materials in vivo should be examined in the future to assess the changes of mechanical properties of restorative materials associated with the dental structure and with the oral environment. This assessment would be necessary to suggest new protocols that allow better maintenance and function of these materials in the oral cavity, resulting in improved quality of life for these patients.

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RESUMO

Objetivo: Este estudo avaliou a influência da radiação do cobalto 60 nas propriedades mecânicas de materiais restauradores. Materiais e Métodos: Dois ionômeros de vidro (Ketac Molar e RelyX Luting), uma resina composta (Filtek Z350) e duas cerâmicas feldspáticas (VITA VMK-95 e StarLight) foram avaliadas. As amostras foram confeccionadas de acordo com as normas da ISO para os testes de flexão de quatro pontos (n=20), tração diametral (n=20) e teste de microdureza; Knoop (KHN) para o ionômero de vidro e resina composta e Vickers (VHN) para a cerâmica (n=10). As amostras foram divididas em dois grupos: irradiado (Ir), submetidas à radiação gama do cobalto com um protocolo similar ao usado para o tratamento de câncer de cabeça e pescoço; e um grupo controle (C) que não recebeu radiação. Resultados: Os dados foram analisados utilizando One Way ANOVA para tração diametral e flexão de quatro pontos ukey (α=,05), para microdureza Knoop e Vickers. A resina composta apresentou e Two Way ANOVA seguido do teste de T uma diminuição nos seus valores de resistência flexural (p<0,003). Para todos os materiais testados, a microdureza não apresentou diferença estatística quanto à região (topo ou base). A irradiação aumentou os valores de microdureza do Ketac Molar (p<0,000) e diminuiu para o RelyX Luting 2 (p<0,002). A VHN não foi influenciada pela irradiação. Conclusão: Irradiação gama influenciou as propriedades mecânicas dos ionômeros de vidro e resina composta, no entanto não alterou as propriedades das cerâmicas avaliadas.

PALAVRAS-CHAVE: Materiais dentários, Radioterapia, Biomecânica.

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