

ORIGINAL ARTICLE

The effects of therapeutic x-ray doses on mechanical, chemical and physical properties of poly methyl methacrylateDERYA OZDEMIR DOGAN¹, YILDIRAY OZGUVEN², GULDEREN KARAKUS³,
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Abstract

Aim. The aim of this study was to investigate the effect of radiation doses very close to the human dose for oral cancers on mechanical, chemical and physical properties for poly methyl-methacrylate (PMMA). **Methods.** PMMA samples were divided into four different groups: no irradiated group, 25-Gy irradiated group, 50-Gy irradiated group and 75-Gy irradiated group. Each group contained nine samples. After 24 h, a three-point loading test was applied to each PMMA groups. The transverse strength and the elastic modulus were calculated using the test results. The results were analyzed statistically by using one-way analysis of variance. The structural characterizations of the PMMA samples were carried out by a Fourier Transform Infrared (FTIR) spectrophotometer to evaluate the chemical structure differences. **Results.** The transverse strength values of 25-Gy, 50-Gy and 75-Gy radiation groups were significantly higher than that of the no radiation group ($p < 0.05$). There was no significant difference among the elastic modulus values of the study groups ($p > 0.05$). The FTIR findings demonstrated that the irradiation process did not change the chemical structure of the PMMA polymeric materials. **Conclusion.** The therapeutic radiation doses increase the mechanical properties of the PMMA; however, the chemical and structural properties have no effect. When the findings of this study are taken into account, it can be said that patients can wear dentures during the radiotherapy.

Key Words: *poly methyl-methacrylate, ionizing radiation, radiotherapy, transverse strength, elastic modulus*

Introduction

During the last decades, there have been substantial improvements in the optimization of radiotherapy in patients with oral cancers [1,2]. The increased use of radiation therapy for the treatment of oral cancer requires that all dentists concerned with the rehabilitation of the oral cancer patients should be familiar with this treatment modality. Misconceptions have developed concerning the advisability of prescribing complete dentures following radiation therapy. However, a clinical study indicates that most radiation patients can wear complete dentures. The need to follow sound prosthodontic techniques is advocated, along with a few modifications related specifically to the radiation

patient. Patient co-operation and meticulous care during and following the placement of dentures are stressed to minimize the risk of tissue necrosis and to preserve the well-being of the patient [3].

During a radiotherapy treatment planning process, the recommended radiotherapy treatment of head and neck cancer patients is usually to wear the removable dental prostheses to avoid deterioration of the anatomical integrity [4].

Poly methyl-methacrylate (PMMA) is the most commonly used polymer for denture base resins. Despite its popularity, however, it is still far from ideal in fulfilling the mechanical requirements of the prosthesis [5]. Many studies showing the effects of ionizing radiation on various restorative dental

materials are in the literature [4,6–11], but there is no research study related to acrylic. As a curative treatment, the radiation dose of the head and neck region is usually 70 Gy [12]. In this region radiotherapy is difficult due to the presence of a lot of the organ at risk (spinal cord, parotid, larynx, mandible, etc.). Therefore, the mandible may take a certain dose of radiation within the limits. Recommended acceptable radiation dose tolerance is the mandible volume of 1% of <70 Gy (V70 <1% of the volume of the mandible). Necessarily, an acceptable radiation dose tolerance is recommended 1% of the mandible volume <75 Gy (V75 <1% of the volume of the mandible). In this case, the radiation dose of dental prostheses can rise up 75 Gy [12]. The aim of this study was to investigate the effect of radiation dose very close to human dose for oral cancers on mechanical, chemical and physical properties of PMMA.

Materials and methods

Polymethyl-methacrylate

Using the heat cured acrylic base resin (Meliodent; Bayer UK Ltd., Newbury, Berkshire, UK), rectangular specimens (65 × 10 × 2.5 mm) were prepared according to ADA No:12 standard. The preparation and polymerization of samples were performed according to producing manufacturer instructions. The samples were divided into four groups; the no irradiated group, the 25-Gy irradiated group, the 50-Gy irradiated group and the 75-Gy irradiated group and each group contained nine test specimens.

Radiation procedure

Before the irradiation, the PMMA samples were kept at room temperature for 30 min in water. Then the PMMA samples were placed at a depth of 5 cm in solid water phantom and between bolus materials. Those were irradiated with the linear accelerator radiotherapy treatment device Varian linear accelerator Clinac 2100 DHX (Varian Medical Systems, Palo Alto, CA, USA) in the radiotherapy clinic. For this process, it was chosen so that a 6 MV energy X-ray was usually used for head and neck radiotherapy. Before the irradiation, the radiotherapy device performed a radiation dose calibration control

procedure. As a result of this control the standard deviation was detected as 0.000,78 cGy for 1 cGy.

Transverse strength and elastic modulus

Twenty-four hours after the irradiation, the three-point loading test was applied to each PMMA group with the Lloyd universal test instrument (H5K-S, Haunsfield Tensometer, Haunsfield Test Equipment Ltd, Redhill, UK). The speed of the instrument is 5 mm/min and the distance between the stands was 50 mm. The breaking force was recorded in Newtons and the transverse strength and elastic modulus values were calculated.

Fourier transform infrared spectrophotometer

The fourier transform infrared spectrophotometer (FTIR) was used to evaluate the chemical structure differences for the PMMA and irradiated PMMA samples. The PMMA polymer and irradiated (25, 50 and 75 Gy) PMMA polymer samples were prepared as the KBr pellets (2 mg sample in 100 mg KBr) and then analyzed in a FTIR (Mattson 1000, Unicam, USA) at wavelengths between 400–4000 cm⁻¹ and at 4 cm⁻¹ resolution.

Statistical analysis

The data of strength test and elastic modulus values were analyzed with the ANOVA test and the Tukey test as a post-hoc test. A *p*-value of less than 0.05 was considered as significant.

Results

Transverse strength and elastic modulus

Table I presents the transverse strength and elastic modulus values of the PMMA specimens. The transverse strength values of the 25-Gy, 50-Gy and 75-Gy radiation groups were significantly higher than that of the no radiation group (*p* < 0.05). The transverse strength values of the 25-Gy, 50-Gy and 75-Gy radiation groups were comparable (*p* > 0.05). There was no significant difference among the elastic modulus values of the study groups (*p* > 0.05).

Table I. Transverse strength and elastic modulus values of PMMA specimens.

	No radiation group (<i>n</i> = 9)	25-Gy radiation group (<i>n</i> = 9)	50-Gy radiation group (<i>n</i> = 9)	75-Gy radiation group (<i>n</i> = 9)
Transverse strength	71.38 ± 3.12 ^a	79.57 ± 5.39	77.68 ± 4.79	81.72 ± 3.86
Elastic modulus	1228.77 ± 141.81	1262.44 ± 163.17	1179.44 ± 144.78	1275.33 ± 176.31

Data were expressed as mean ± SD.

^a*p* < 0.05 vs 25-Gy radiation, 50-Gy radiation and 75-Gy radiation groups.

Fourier transform infrared spectrophotometer

Figure 1 shows that the PMMA polymer and the irradiated (25, 50 and 75 Gy) PMMA polymer were quite identical in appearance related to the FTIR spectra. Except for one peak at 2375 cm^{-1} , which arose from CO_2 , all of the other peaks were similar. The fingerprint characteristic frequency of O=C=O stretch at 1729 cm^{-1} and 1450 cm^{-1} were detected in the spectrum, which could originate from the ester groups in the PMMA and irradiated PMMA side chains [13,14]. Similar to the other peaks as follows: The bands at 3000 cm^{-1} and 2900 cm^{-1} correspond to the C-H stretching of the CH_3 , methyl group of the PMMA and the irradiated PMMA, the bands at 1300 cm^{-1} and 1450 cm^{-1} were corresponding to the C-H symmetric and the asymmetric stretching vibration modes, respectively. The 1240 cm^{-1} frequency vibration was related to CH_2 , the methylene group, and the 1150 cm^{-1} frequency vibration band corresponds to the C-O ester group. In addition, the C-C stretching frequency vibration bands were at 1000 cm^{-1} and 800 cm^{-1} [14]. The presence or absence of any other peaks were not detected in the spectrum of the PMMA and all of the three irradiated PMMA spectra except 2375 cm^{-1} , which has arisen from CO_2 (concerning experimental conditions or preparing KBr pellets). The FTIR findings demonstrate that the irradiation process does not change the chemical structure of the PMMA polymeric materials.

The structural characterization of synthetic (PMMA) polymer and 25-, 50- and 75-Gy-irradiated

PMMA polymers was carried out by the fourier transform infrared spectrophotometer (Figure 1). Black, red and yellow curves shows 25, 50 and 75 Gy, respectively, and the blue curve shows no irradiation.

Discussion

In this research study of PMMA samples, before and after the irradiation procedure, the transverse strength and the elastic modulus measurement were performed. Furthermore, before and after the irradiation procedure, the chemical structure of PMMA samples was evaluated by the FTIR and the surface morphological image were examined by the SEM. Since no change on chemical structure of PMMA was seen in the FTIR evaluation, there was no need to evaluate by Nuclear Magnetic Resonance (H-NMR) for the evaluation of additional changes on chemical structure.

The PMMA is the most commonly used polymer for denture base resins. Despite its popularity, it is still far from ideal in fulfilling the mechanical requirements of the prosthesis [5]. Little is known about the direct exposure of ionizing radiation on dental materials [4,6–8,15–17] and the exposure results are still unclear [17]. As patients will certainly have a variety of intra-oral dental restorative materials, any interactive effects between the X radiations with such dental materials during their radiotherapy will be clinically significant, if the mechanical and chemical properties of the materials are adversely affected [9].

In the studies where high-energy ionizing radiations are directly applied on dental materials, as gamma

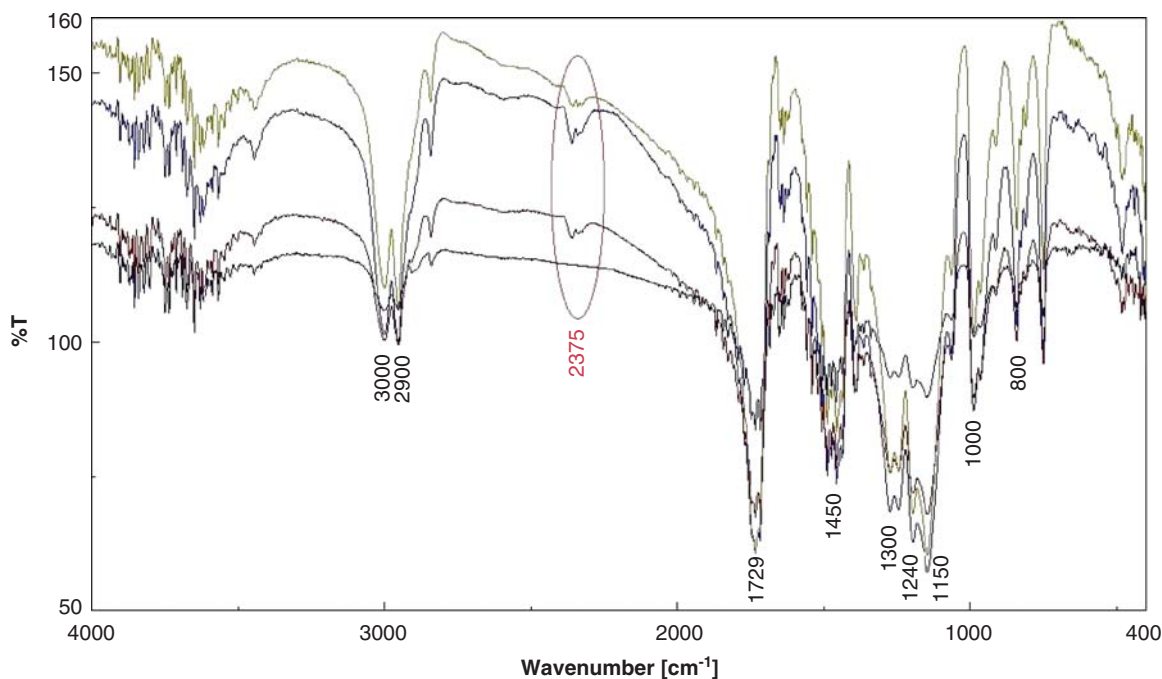


Figure 1. The structural characterization of synthetic (PMMA) polymer and 25-, 50- and 75-Gy- irradiated PMMA polymers by Fourier Transform Infrared Spectrophotometry.

beams [7,8,15,16] or electron radiation [4,15], some mechanical properties of these dental materials change proportionally to the increase of the radiation dose. Electron-beam post-curing is widely used to improve the mechanical properties of polymers [5]. It is demonstrated that irradiation initiates the radical building of all components of a polymer in contrast to mere chemical reaction [18]. In the literature [19–21], the PMMA is often described as a thermoplastic polymer which tends more to chain breakage during irradiation [20]. Behr et al. [22] investigated the influence of electron-beam irradiation on mostly PMMA-based denture base resins. In their study, the mechanical properties of the polymers improved using 10 MeV with a dose of 25 kGy and with 100 kGy using 4.5 MeV. However, they found that the mechanical improvements were low [5]. During a chemical reaction, radicals that induce chain linkage are initiated from several distinct points. The polymeric chain increases, but the chain linkage is not equally distributed in the polymer. It has been demonstrated that irradiation initiates the radical building of all components of a polymer in contrast to mere chemical reaction [22]. For that reason, the entire polymer may simultaneously be newly arranged and cross-linked when irradiated. However, these effects occur at high dose such as 25–250 kGy. However, little is known about the effect of therapeutic dose ionizing radiation on dental materials [4,6–8,15–17]. These restricted research studies were mainly concerned with the dental composite [8,10,11,23], however there is no research study for therapeutic dose effects on the PMMA.

At radiotherapy of the head and neck, an acceptable radiation dose tolerance for mandible 1% of the mandibular volume (<75 Gy (V75 <1% of the volume of the mandible) is recommended [12]. However, together with healthy tissue, the dental restorations may be irradiated during fractionation and can receive a significant amount of the radiation dose [1,2]. Therefore, dental prostheses in the mouth during radiotherapy may take up to 75 Gy radiation doses [12].

In the present study, the radiation dose is chosen similar to some of the previous studies [8–11,23]. In other studies the used radiation doses were higher than the ones used in the present study [4–6,8,15,22]. These doses are not compatible to the ones used in radiotherapy of head and neck tumors [1,2].

Whereas there are a lot of studies on whether patients can wear removable denture or not during the whole radiotherapy treatment period [3,24], there is not any specific research on whether it can be worn or not for the instant when patients are exposed to rays during the radiotherapy. Patients generally are cured by radiotherapy with their removable prosthesis.

The PMMA which is very important for manufacturing prosthesis depends on irradiation procedure mechanic properties such as transverse strength being

increased, whereas elastic modules do not change. The FTIR measurements related to chemical structure and SEM photographs related to morphological surface characteristic do not change after irradiation.

This research study demonstrates that, during radiotherapy for head and neck cancer patients, it is not essential that removable prostheses are taken out of the mouth. When patients wear the dentures during the therapy, a partial increase of the mechanical properties can occur, but some chemical and structural properties may not be affected. When our findings are taken into account, it can be said that, during radiotherapy there is no need to remove the prosthesis from the mouth.

Conclusions

Investigating the effect of radiation doses very close to the human dose for oral cancers on mechanical, chemical and physical properties of poly methyl-methacrylate (PMMA) showed that the therapeutic radiation doses increased the mechanical properties of the PMMA; however, the chemical and structural properties had no effect. When the findings of this study are taken into account, it can be said that patients can wear dentures during radiotherapy. Further studies will also be supported by the clinical trials.

Declaration of interest: The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

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