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Evaluation of the Effectiveness of Polyether Silicone-based and Polyvinyl Siloxane Dental Impression Materials for Shielding Scattered Radiation During Radiotherapy

Radyoterapi Sırasında Saçılan Radyasyona Karşı Koruyucu Olarak Polieter Silikon Bazlı ve Polivinil Siloksan Diş Ölçü Malzemelerinin Etkinliğinin Değerlendirilmesi

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Abstract

Objective: Radiation-induced oral mucositis is a major problem associated with radiotherapy. This study aimed to investigate the effectiveness of polyether silicone-based (PE) and polyvinyl siloxane (PVS) impression materials in protecting adjacent tissues from radiation scattered from dental materials.

Materials and Methods: Amalgam, zirconium, and titanium dental material specimens were covered with 5 mm PE and PVS in the study group. The dental materials were placed in a linear accelerator device at a distance of 100 cm from the radiation source and coincided with a field size of 15x15 mm. Samples placed perpendicular to the central beam were irradiated with 6 MV photons at a fractional daily therapeutic radiation dose of 2 Gy. Thermoluminescent dosimeters (TLD-100) placed 90 degrees lateral to the specimens were used to record the scattered dose data. In the control group, uncovered dental materials were irradiated, and scattered doses were measured by TLD. The TLD data of the study and control groups were compared by independent t-test to analyze the shielding effect of PE and PVS. In addition, the photon stopper properties of PE and PVS were compared. The photon interaction parameters and effective atomic numbers of dental materials were calculated.

Results: It was calculated that the PE and PVS significantly prevent the dose enhancement caused by dental materials ($p<0.05$). There was no difference between impression materials in the photon-stopping properties ($p>0.05$).

Conclusion: PE and PVS can be used as scatter dose shields for the 2 Gy daily fractional dose. This study demonstrates the radiation-shielding properties of PE for the first time.

Keywords: Amalgam, dental materials, dental impression materials, X-rays, zirconium

Öz

Amaç: Radyasyona bağlı oral mukozit, radyoterapinin önemli bir sorunudur. Bu çalışmanın amacı, polieter silikon bazlı (PE) ve polivinil siloksan ölçü materyallerinin (PVS) komşu dokuları dental materyallerden saçılan radyasyondan korumadaki etkinliğini araştırmaktır.

Gereç ve Yöntemler: Çalışma grubundaki amalgam, zirkonyum ve titanyum dental materyal örnekleri 5 mm PE ve PVS ile kaplandı. Lineer bir hızlandırıcı cihaza dental materyaller radyasyon kaynağından 100 cm uzakta ve 15x15 mm alan boyutuna denk gelicek şekilde yerleştirildi. Merkezi ışına dik olarak yerleştirilen örnekler 2 Gy fraksiyonel günlük terapötik radyasyon dozu ile 6 MV fotonla ışınlandı. Saçılan doz verilerinin kaydedilmesi için numunelerin 90 derece lateraline yerleştirilen termolüminesan dozimetreler (TLD-100) kullanıldı. Kontrol grubunda ise üzeri kaplanmamış dental materyaller ışınlandı ve TLD ile saçılan doz ölçüldü. Çalışma ve kontrol

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gruplarının TLD verileri, PE ve PVS'nin koruyucu etkisini analiz etmek için bağımsız t-testi ile karşılaştırıldı. Ayrıca PE ve PVS'nin foton durdurucu özellikleri karşılaştırıldı. Dental materyallerin foton etkileşim parametreleri ve etkin atom numaraları hesaplandı.

Bulgular: PE ve PVS'nin dental materyallerin neden olduğu doz artışını önemli ölçüde önlediği hesaplandı (p<0,05). Foton durdurma özelliklerinde ölçü materyalleri arasında fark yoktu (p>0,05).

Sonuç: PE ve PVS, 2 Gy günlük fraksiyonel doz için bir saçılan radyasyon kalkanı olarak kullanılabilir. Bu çalışma, PE'nin radyasyon koruma özelliğini ilk kez göstermektedir.

Anahtar Kelimeler: Amalgam, dental materyal, dental ölçü malzemeleri, X-ışınları, zirkonyum

Introduction

Radiation-induced oral mucositis is a tissue damage that starts as acute inflammation in the oral mucosa, tongue, and pharynx after exposure between 7 and 98 days (1). As a result of these, oral pain was reported in 69% and dysphagia in 56% of patients with radiation-induced oral mucositis. In addition, it was shown that 53% of the patients had a history of opioid use, 15% of them had a feeding tube inserted, and 11-16% of them had a history of changing or discontinuing treatment due to oral mucositis. It can progress to an acute life-threatening stage because of reduced food and water intake (2,3).

In this context, dental materials including metals (e.g., gold and silver/mercury alloys) can increase the radiation dose up to 2 times in the region adjacent to the dental restoration (4). Since dental materials have higher atomic numbers than soft tissues, they cause the reflection of electrons during radiotherapy (RT). Regard, the radiation dose enhancement often leads to severe mucositis or osteoradionecrosis, especially in patients suffering from oral tumors (5).

There are studies on the oral stents and plates used to protect surrounding tissues to reduce or delay complications arising from that backscatter radiation (6-11). In reported studies, it has been stated that the use of intraoral stents reduces the RT side effects such as mucositis, osteoradionecrosis, and xerostomia (6-9). Methyl methacrylate and hydro-plastic materials (7,8) new polymer-based lightweight, non-toxic composite materials such as polypropylene, polystyrene, and polyethylene are widely used in the production of stents for radiation protection (10,11). However, the effectiveness of the polyether (PE) impressions materials protecting healthy oral tissues from undesirable radiation effects has not been presented yet.

The present study aimed to investigate the use of PE and polyvinyl siloxane (PVS) in different thicknesses as radiation shielding that have advantages such as being biocompatible, non-irritant, easy to apply, accessible, inexpensive, and reproducible before each fraction of the RT. The null hypothesis of the study was that PE and PVS did not prevent scattered radiation caused by DMs.

Materials and Methods

Preparing of the Impression Material Samples (IMs)

The PE silicone-based IM (PE: Impregum Penta H-DuoSoft Quick, 3M ESPE) and PVS IM (PVS: Betasil Vario Implant, Muller-Omicron Gmbh & Co KG) were used in the study as a radiation shield. Firstly, cylindrical plastic templates were prepared to provide 5 mm thick IMs all over the DM. Another cylindrical plastic block of 5 mm diameter, and 5 mm height was placed in the center of the template base to obtain a cavity for use in placing the DM samples (amalgam, zirconium, and titanium).

IMs were obtained by mixing base and catalyst. The chemical composition of the PE (Impregum Penta H-DuoSoft Quick, 3M ESPE) includes PE macromer, fillers, triglycerides, and plasticizers for the base, and initiator, fillers, plasticizers for the catalyst. The base material of the PVS (Betasil Vario Implant, Muller-Omicron Gmbh & Co KG) contains a polymethyl hydrogen siloxane copolymer and amorphous silica. Additionally, the catalyst of the PVS includes the vinyl-terminated polydimethylsiloxane and chloroplatinic acid. Both IMs were mixed by an automatic mixing unit (Pentamix II; 3M ESPE) in offered mixture ratios due to the recommendations of the manufacturer. The mixed IMs were molded into these templates and kept in the templates until they hardened. Then, hardened IMs were removed from the templates. Every IM covered each point of the DM except the top surface of the hardened IMs because, the central beam was directed to the upper surface of the DM (Figure 1).

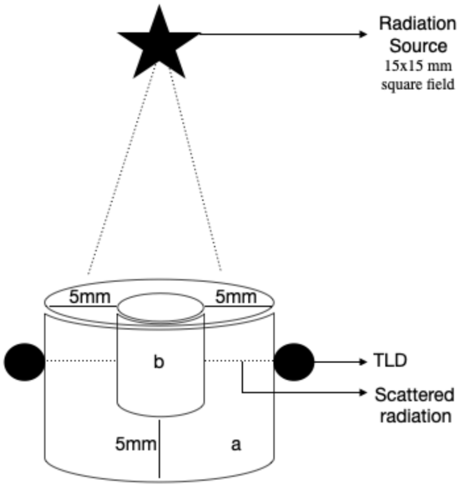

Figure 1. Presents the set-ups included dental materials covered dental impression materials. a: is the IM covering the dental materials; b: shows the dental material in 5 mm diameter, and 5 mm height

TLD: Thermoluminescent dosimeters

Scatter radiation was measured in the lateral area by TLD. Therefore, 120 IMs [PE (n=60), PVS (n=60)] were produced for the study group in total.

Preparing of the Dental Samples

A total of 180 DMs in a cylindrical form in 5 mm diameter and 5 mm height were prepared for PE and PVS groups. Sixty dental material samples [amalgam (n=20), zirconium (n=20), and implant (n=20)] were produced for PE, and 60 DM specimens for the PVS group. In addition, 60 DMs were prepared for the control group.

The amalgam (Southern Dental Industries Ltd., SDI, Australia) and zirconium blanks (Nacera Pearl 1, Doceram GmbH, Dortmund, Germany) in a cylindrical shape with a diameter of 5 mm and a height of 5 mm were prepared. To prepare amalgam samples, the powdered alloy encapsulated amalgam with liquid mercury was mixed with an amalgamator to form an amalgam putty. This softened amalgam putty was placed and shaped into the previously prepared cylindrical mold (5 mm diameter and 5 mm height), where it quickly hardened into a solid filling. For obtaining zirconium samples, single-brand monolithic zirconium blocs (Nacera Pearl 1, Doceram Medical Ceramics, Germany) were prepared with computer-aided design/computer-aided manufacturing (Amanngirbach, Ceramill Motion, Germany) and sintered due to the instructions of the manufacturer. The final dimensions of the samples were controlled with a digital compass (Mitutoyo, Japan). For titanium samples, 5 mm diameter titanium implants (Astra Tech Implant System) were used.

Control Group

To calculate the shielding effect of the IMs, uncovered amalgam (n=20), zirconium (n=20), and titanium (n=20) samples were irradiated by 6 MV, and the scattered radiation was recorded the same as other set-ups. The percentage dose increase (PDI) caused by DMs was calculated. For this, tissue equivalent bolus (without DM and IMs) was irradiated, and the base dose calculated by TLD was placed in the same place as the study groups. The dose increase caused by DMs was calculated by the PDI formula.

The PDI according to TLD data were calculated by using the following formula:

$$PDI = \frac{\text{Control group (DM without IMs)} - \text{Base dose (Bolus without IMs and DMs)}}{\text{Base dose}} X\ 100$$

Radiation Dose Measurement

Thermoluminescent dosimeters (TLD-100; Harshaw Chemical Company) having 3.2×3.2×0.89 mm^3 sizes, and 2 mm spatial resolution was used for recording the scattered dose data. The TLD-100s were calibrated by Win-TLD software before every irradiation process. TLDs were placed in the bolus at the lateral side of the IMs. Three TLDs were placed around each setup. After every irradiation process TLD chips were read by TLD reader RE 2000A (Mirion), and Win-TLD Software.

XCOM Program

The theoretical mass attenuation coefficients (μ/ρ) for the DMs (amalgam, zirconium, and implant) were obtained from the XCOM computer program (Version 3.1., National Instute of Standards and Technology, America). The program can determine to get information about the interaction between DMs and photons (12). This program can determine the μ/ρ of an element, compound, and mixture at different energy levels (0.001 up to 105 MeV). In this study μ/ρ of the DMs was calculated according to their prescriptions given by the manufacturer at 0.2, 0.4, 0.6, 0.8, 1, 1.5, 2, 2.5, 3, 3.5, 4, 4.5, 5, 5.5, and 6 MeV photon energies.

Irradiation Process

The set-ups were embedded in tissue-equivalent bolus material (Superflab Bolus 30×30×1.0 cm) simulating the soft tissue. Besides, a 15-mm-thick layer of bolus materials were placed on the superior and inferior surface of the specimens. Under the bolus material, a 10 cm RW3 solid water phantom (30 cm x 30 cm x 1 cm, Slab Phantom, Sun Nuclear Corporation, Melbourne, Florida) was used to prevent the backscattering factor. The samples irradiated in a linear accelerator device (Clinac iX, RapidARC, Varian Medical Systems, USA) operated at 6 MV photons. Specimens were placed perpendicular to the beam collimated to a 15×15 mm square field. The surfaces of the DMs were located 100 cm from the radiation source. Diagram of the experimental design is shown in Figure 2.

Defining the Theoretical Properties of DMs

The Phy-X/ZeXTRa software program was used to calculate the effective atomic numbers for photon energy absorption (ZPEAeff) of DMs according to the 6 MV photon energy and elemental compound of the materials (13).

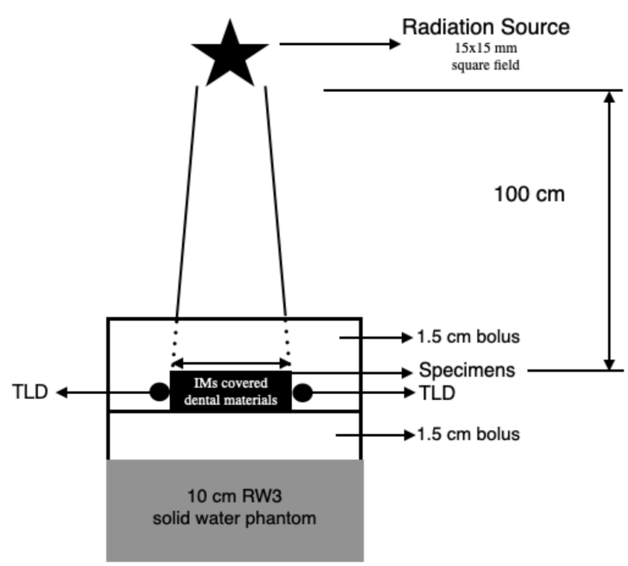

Figure 2. Diagram of experimental design
TLD: Thermoluminescent dosimeters, IM: Impression material sample

Table 1. Presents the recorded data on TLDs and PDI caused by dental materials and, ZPEAeff values due to dental materials. The TLD data are compatible with the calculated ZPEAeff values which describe the absorbsion of the encountered photon energy

Control group	Mean (mSv)	Std. deviation	Std. Error	Min.	Max.	PDI%	ZPEAeff
Base dose	9.042	0.295	0.170	8.77	9.36	-	-
Amalgam	9.486	0.053	0.031	9.43	9.53	4.910	41.77
Zirconium	10.725	0.643	0.371	10.17	11.43	18.613	29.36
Titanium	11.898	2.431	1.403	9.42	14.28	31.585	21.54

TLD: Thermoluminescent dosimeters, PDI: Percentage dose increase, Std.: Standard, min: Minimum, max: Maximum

Statistical Analysis

Statistical analysis was performed using SPSS (IBM Corp., Windows, version 22.0). Independent t-test was used to compare the TLD data of the control group and study group. Besides, independent t-test was used to compare different IMs effectiveness. P-values less than 0.05 were considered statistically significant.

Results

Value of Scattered Radiation from the DM Surface and Data of the XCOM

The maximum PDI was presented for the titanium calculated with a value of 31.585% compared to the dose of the control group. It is shown that the TLD values, and ZPEAeff data are in a harmony (Table 1). As the ZPEAeff value indicating photon-energy absorption calculated by Phy-X/ZeXTRa diminished, the reported data in TLD increased. These results support the accuracy of the values measured in TLDs.

As seen in Table 2, the μ/ρ of the amalgam was found as higher than the other materials in each photon energy line. The mass absorption coefficients for amalgam, zirconium, and titanium in descending order.

Evaluation of the Protective Properties of IMs

It was calculated that 5 mm IMs significantly prevent the dose enhancement caused by all three DMs ($p<0.05$). Table 3 shows the dose enhancements caused by three DMs. No difference was measured between the photon-stopping properties of the two IMs ($p>0.05$) (Table 3).

Table 2. Presents the μ/ρ values calculated by XCOM. It is shown that μ/ρ values are higher in amalgam group that other material groups in between fraction of 0.2-6.0 MeV photon energy

Energy (MeV)	Amalgam (XCOM) (cm^2/g)	Zirconium (XCOM) (cm^2/g)	Titanium (XCOM) (cm^2/g)
0.2	0.58800	0.19820	0.13090
0.4	0.16240	0.10020	0.09089
0.6	0.09938	0.07831	0.07541
0.8	0.07632	0.06698	0.06584
1.0	0.06406	0.05949	0.05902
1.5	0.04944	0.04821	0.04810
2.0	0.04366	0.04224	0.04186
2.5	0.04085	0.03863	0.03790
3.0	0.03934	0.03631	0.03512
3.5	0.03857	0.03473	0.03314
4.0	0.03823	0.03362	0.03168
4.5	0.03817	0.03285	0.03058
5.0	0.03829	0.03230	0.02972
5.5	0.03852	0.03192	0.02906
6.0	0.03885	0.03167	0.02855

Table 3. Shows the comparison the TLD values capturing the transmissed radiation amount from PE and PVS in the each of dental material groups. Table presents that 5 mm PE and PVS increased the scattered dose when compared TLD data of control group. PE*PVS column indicate that there is not any difference between impression materials about shielding of the scattered radiation dose result from the dental materials in 6 MeV

	Control	5 mm PE	p-value	5 mm PVS	p-value	p-value (PE*PVS)
Amalgam	9.48±0.05	5.86±0.30	0.010	5.51±0.60	0.004	1.000
Zirconium	10.72±0.64	5.96±1.30	0.008	6.57±1.24	0.003	0.719
Titanium	11.89±2.43	6.75±1.38	0.033	6.07±1.36	0.032	1.000

TLD: Thermoluminescent dosimeters, PE: Polyether silicone-based, PVS: Polyvinyl siloxane

Discussions

The X-ray and gamma rays (in a wide energy range) interact with matter through the photoelectric effect, coherent scattering, incoherent scattering, and pair production (14,15). In this way, DMs interact with the X-rays and cause to secondary electrons detached from the atomic shield of the materials. These seconder electrons may cause dose enhancement especially in the tissues adjacent to dental alloys which is results in mucositis.

The interaction parameters of the radiations (X-ray, gamma, neutron, etc) with materials depends on the effective atomic number (Zeff), and μ/ρ considered as a type of absorption cross-section (15). The Zeff depends on the energy, type of the incident radiation, and the density of the material, that plays an important role to determine the effects of X-rays in the matter (16). The μ/ρ is a value that gives the average number of interactions between incident photons and material. As a result of these interactions, amount of average photon energy transferred in kinetic energy can be measured by μ/ρ. The μ/ρ has an essential role in estimating absorbed dose in medical physics and other fields used irradiation technologies such as industrial and agricultural studies (17).

The value of the ZPEAeff obtained using μ/ρ s may be attributed to the pair production, photoelectric effect, coherent scattering, and incoherent scattering (15). Regard, the ZPEAeff values of the DMs were calculated in this study. The results were compatible with the Phy-X/ZeXTRa database and recorded TLD values. It should be noted that the percentage of components in the same DMs may differ between commercial products.

In a previous study conducted by an H&N anthropomorphic and IMRT technic, it was reported that the backscatter dose of the dental amalgam measured by TLD, causes dose increase in the parotid glands (up to 24.38%) and a reduction in the mean dose (up to -6.25%). The closest position of the parotid gland to the tooth was 6.1 cm, while the farthest position was 10.9 cm from the tooth with amalgam in the H&N phantom (18). But in this current study, it was observed that the dose enhancement at a distance of 5 mm from amalgam was 5% (18). Although both studies showed a dose enhancement due to the amalgam, the differences in PDI values may be caused by the different RT methods.

Regard, the intraoral stents have been used to decrease the potentially adverse effect of the irradiation in the normal tissues outside the planned target volume by increasing the distance between the maxilla and mandible or depressing to the healthy tissues such as the tongue (19). This method can set apart the healthy tissues from the irradiation field. Additionally, it leads to the stabilization of the mandible in each fraction of RT (6). Besides oral stents, other devices which easily adapt to anatomical structures can be used to separate the tumor area by covering healthy tissues. Due to fact that their easy adaptable properties, the effectiveness of the IMs as an X-ray stopper was evaluated. Besides the IMs are considered as a useful material because they are practical for manipulation, soft and non-irritating for tissues, low cost, easy and rapid. Additionally, they don't need any laboratory process for creating.

For the protection of the oral mucosa from the radiation-induced radicals, we offer using a new prepared IM for every fractional irradiation. Additionally, to avoid the radioactivation of IMs, Kawamura et al. (8) offered the taking out the irradiated PVS from the patient's mouth within 1 minute. Moreover, researchers reported that the radioactivation of the PVS was less than 1 μSv/h after 2 Gy-proton irradiation and decreased to the background level after 30 minutes (8). One of the potential criticisms of this current study would be using the only TLDs for dose measurements. If another dose calculation method had been used additionally and compared with the results of TLDs, more confident results would have been obtained. Regard, to minimize uncertainties of all values, dose measurements were made with TLDs three times from three different regions for each set-up.

Conclusions

According to the knowledge of the authors, no reports have been published confirming in advance PE material safety and impact thoroughly on preventing the backscatter radiation dose caused by the interaction of the X-ray with DMs. PE and PVS could be used in patients with oral cancer to reduce the occurrence of oral complications such as radiation mucositis. But it should be noted that we believe it is very important to examine the use of the material in a comprehensive approach before bringing the technique to the clinic application.

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Ethics

Ethics Committee Approval: Ethics committee approval was not obtained since the study was carried out in an experimental environment on materials that did not belong to any living organism.

Informed Consent: Informed consent is not required.

Peer-review: Internally and externally peer-reviewed.

Authorship Contributions

Surgical and Medical Practices: Y.D., Ç.A., E.I.A., Concept: Y.D., Ç.A., E.I.A., Design: Y.D., Ç.A., E.I.A., Data Collection or Processing: Y.D., Ç.A., E.I.A., Analysis or Interpretation:

Y.D., Ç.A., E.I.A., Literature Search: Y.D., Ç.A., E.I.A., Writing: Y.D., Ç.A., E.I.A.

Conflict of Interest: No conflict of interest was declared by the authors.

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