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Investigation of Dosage Distributions of Polyvinyl Siloxane Dental Impression Shields for Head and Neck Radiotherapy with Thermoluminances Dosimeters

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ABSTRACT

Objective: This study aimed to assess the effects of denture materials on dose distribution on a head and neck radiotherapy-appropriate model and calculate the thickness of a stent by polyvinyl siloxane dental impression material for shielding scattered radiation from dental restorations.

Methods: In the first step of the study, 5mm diameter and 5mm height of cylindrical dental material of titanium, zirconia lithium disilicate were irradiated with 6-Megavoltage photons from a clinical linear accelerator. In the second step, dental materials at the center of polyvinyl siloxane thicknesses of 5, 10, and 20mm were irradiated with 2 Gray and 10 Gray fractional doses. Measurements were made using three thermoluminescent dosimeters positioned laterally. The percentage backscattered dose and percentage dose decrease values were calculated to interpret the results.

Results: According to the result, dosages scattered from dental materials increased for samples irradiated with 2Gy; a decreased dose was reported for samples irradiated with a 10Gy. 5mm PVS samples provided higher dose attenuation than others. Regardless of dental material, it is seen that the attenuation intensities calculated from TLD-100 dosimeters ranged from 22.7 to 38,62 for 2Gy, and 10.01 to 38,87 for 10Gy.

Conclusion: Dental material alters the scattered radiation. In irradiated head and neck cancer patients, a 5mm thick guard is sufficient to prevent radiation diffused from dental materials in clinical usage.

Keywords: Radiotherapy, polyvinylsiloxane, TLD, dose distribution.

1. INTRODUCTION

Radiotherapy is a fundamental part of cancer treatment protocols. It is very competent and helps to take control of the tumor. However, its toxic effects on healthy tissues within the irradiation area are negative aspects of treatment also. If the targeted area is around the oral cavity, oral functions like eating and chewing of cancer patients become painful, negatively affecting life quality (1). Radiotherapy in head and neck cancers (HNRT) is challenging both clinicians and patients due to dental materials such as amalgam, dental ceramic, and titanium. The tooth with restoration made from different dental materials acts as a heterogeneous substrate inducing secondary electron scattering in different ways, primarily backward. Besides, an increase in out-of-field exposure may raise the incidence of radiotherapy-related secondary malignancies. Thereby they convert contamination of neighbor healthy tissues with extra doses of radiation (2). Enhanced radiation dosage is a crucial determinant of dental complications as far as the dimension and position of the irradiating areas (3).

In the studies that concentrated on dental restorative materials, researchers have investigated the interaction of radiotherapy with teeth, gold, amalgam, composite, ceramic, zirconia, and titanium (2,4–6). While Reitemeier *et al.*(7) said that dental materials might produce up to a 2-fold increase in excess radiation, Chin *et al*. (5). declared increased scattering radiation dosage approximately four times more than other materials studied. All studies above recommended that if there are restored teeth with dental materials in the targeted area during HNRT, surrounding tissue adjacent to these teeth should be protected from backscattering radiation stem from the presence of restoration itself. A protective intraoral stent could eliminate the adverse effects that developed early stage of treatment and lasted three-four weeks even after treatment completion related to HNRT (8–10). The use of a spacer with shielding capacity can avoid dose augmentation induced by backscatter radiation from dental materials (7).

Since their excellent chemical and mechanical durability, polysiloxane polymers have been employed for radiation

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protection studies in nuclear applications (11). Nevertheless, there are a few studies about the usefulness and effectiveness of polyvinyl siloxane (PVS) impression material with different metal additives as a shielding material (12,13). According to these studies, PVS-metal composites are equally effective as traditional shielding alloys. Authors preferred PVS over conventional materials owing to advantages of PVS like the ease and fast of fabricating, not necessarily precise equipment, and techniques, and more comfortable for patients. Although a PVS-metal composite stent may be effective in the case of intraoral radiotherapy adjacent teeth with dental restorations, the metal in the composite structure also creates considerable backscattered radiation. In another research, Kawamura used regular PVS impression material as a proton beam stopper to protect the tongue during proton treatment of a 75-year-old patient with gingival squamous cell carcinoma (14). He compared dose-volume histograms of the tongue with and without PVS and the relative linear stopping power of PVS using converted CT data and a model simulation. At the end of the study, the authors declared that PVS might be a promising proton beam stopper option.

As a result of the literature review, no study has been found on whether PVS dental impression material efficiently blocks the radiation emitted by dental materials. Thus, the current study was designed to (1) determine the effects of contemporary denture materials on dose distribution on an appropriate model for HNRT and (2) identify the thickness of a stent made from PVS dental impression material for shielding backscattered radiation from dental restorations.

2.METHODS

This study researched whether high and medium viscosity PVS impression materials could attenuate or block the scattering radiation from dental materials. The experimental setup which was followed during the investigation is shown in Fig 1.

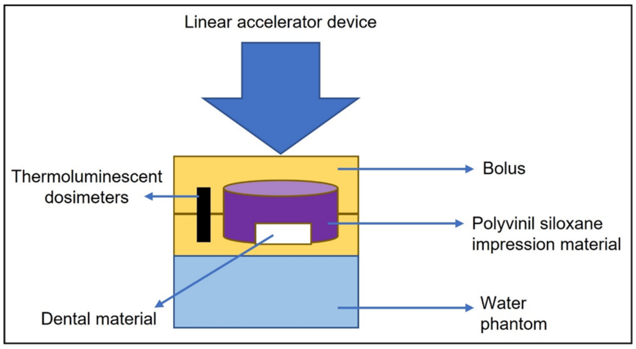

Figure 1. *An illustration of the experimental design*

To imitate the dental restorations, cylindrical specimens with 5mm diameter and 5mm height were produced in equal amounts for each group of dental material. Highly translucent zirconia (3Y-TZP) blocks (Nacera Pearl 1, Doceram Medical Ceramics, Germany) were cut by CAD/CAM (Ceramill Motion; Amanngirbach, Germany) and sintered according to the manufacturer's recommendations for monolithic zirconium specimens (n=5). Titanium specimens (n=5) were produced from Grade 4 pure titanium (Astra Tech Implant System; Dentsply Sirona, Charlotte, NC, USA). The lithium disilicate specimens (n=5) were fabricated by milling out of blocks with CAD/CAM (IPS e.max CAD; Ivoclar Vivadent, Schaan, Liechtenstein).

For this study, it was decided to prepare the samples for both high-viscosity (Kulzer, Variotime Dynamix Heavy Tray) and medium-viscosity (Kulzer, Monophase/Dynamix Monophase) groups with 5mm, 10mm, and 20mm thicknesses around the dental materials PVS-based elastomeric impression materials were obtained using a device (Pentamix®; ESPE) that mixes the base and catalyst homogeneously following the manufacturer's instructions and put into the mold (Fig 2). In the experimental setup, the sample of the study group containing dental material at the center of PVS was placed in soft tissue-equivalent bolus material (Superflab Bolus Material; CNMC Co, Nashville, TN, USA) (Fig 3).

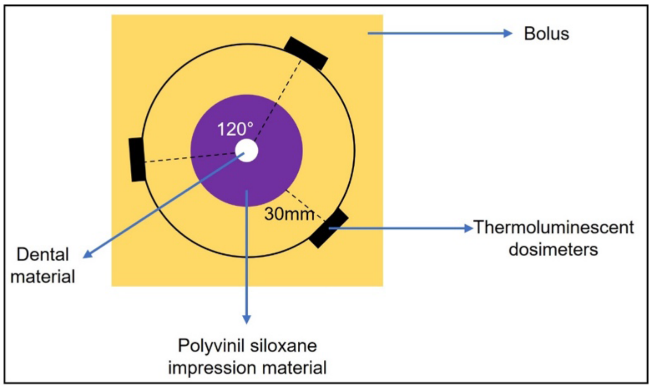

Figure 2. *An illustration of TLD dosimeter's locations*

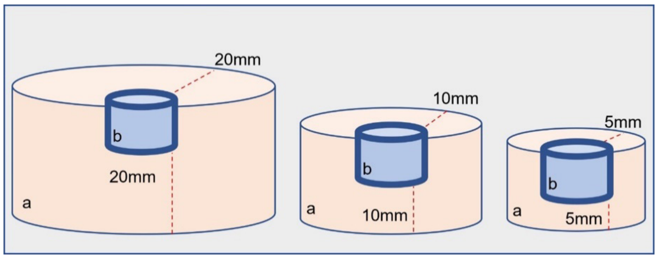

Figure 3. *An illustration of dental material specimens within polyvinyl siloxane*

Under the bolus, the RW3 solid water phantom was put to stop backscattering. Then, the setup prepared separately for each sample was positioned on the radiotherapy device where the central beam was right in the center of the dental material during irradiation. A 6-MV photon beam was applied with a clinical linear accelerator (Clinac Ix; RapidARC, Varian Medical Systems, USA) (5). The radiation source was positioned to be away 100 cm from the impression material. While irradiation, the source-skin distance (SSD) technique was performed at the field of 15x15mm doses of 2Gy and 10Gy, compatible with The National Comprehensive Cancer Network (NCCN) Guidelines which recommend applying daily and weekly fractional therapeutic radiation in the clinical design of HNRT. The dimension of a pre-calibrated thermoluminescent dosimeter (TLD-100; Harshaw Chemical Company, Solon, OH) was 3.2x3.2x0.89mm, and its spatial resolution was 2mm. TLD was positioned in the lateral direction of the dental material's outer line around a 30mm radius circle with an angle of 120 apart from each other (Fig 4).

Figure 4. *Polyvinyl siloxane samples with a space at the center for dental material: High-viscosity PVS (Grey) and Medium-viscosity PVS (Pink)*

There were three TLD-100 on a ring with a 30mm radius. Therefore, the distance effect for scattering, which is inversely proportional to the square, was eliminated. In this way, the comparison was made more accurately. The Harshaw TLD reader read TLD-100 dosimeters. This process was repeated three times for each sample. The setup in the control group was produced by titanium, zirconia, and lithium disilicate without PVS impression material.

In this study, interpreted the below situations were interpreted:

(1) Percentage dose difference (PDD) was calculated in the presence of a dental restoration material by the following formula:

PDD = (D2-D1 / D1) x 100

(2) Percentage dose difference (PDD) was calculated in the presence of a PVS around the dental restoration material by the following formula:

PDD = ((D3-D2) / D2) x 100 (15).

D1: the photon dosage in only soft tissue-equivalent bolus material, **D2:** the photon dosage in the presence of a dental restoration material, and **D3:** the photon dosage in the presence of a PVS around the dental restoration material at the exact precise location, respectively.

3. RESULTS

For each dose energy, the precision of the TLD measurements was quantified by calculating the mean response, standard deviation, and percent dose differences for the dental material's group and PVS height.

In the first part of our study, we evaluated the impact of some widely used denture materials on dose distribution in HNRT by medical linac and a TLD dosimetry system. The values of dose distribution in the case of different dental restoration, titanium, zirconia, and lithium disilicate are presented in Table 1.

According to the result, scattered doses increased for samples irradiated with 2Gy; a decreased dose was reported for samples irradiated with a 10Gy. Dose increase was found at 22.57%, 12.32%, and 7.83% for titanium, zirconia, and lithium disilicate, respectively. In contrast, dose decrease was recorded as 20.27%, 12%, and 10.22% for titanium, lithium disilicate, and zirconia, respectively (Table 1).

In the second part of our research, dosimetric distribution after simulated HNRT in the presence of dental material and PVS impression material was evaluated. The dependency on the thickness of PVS specimens concerning dose differences for 2Gy and 10Gy fractional radiation doses is presented in Table 2 and Table 3, respectively.

Table 1. *Absolute backscatter dose and percent dose differences in the presence of different dental restoration materials for 2Gy and 10 Gy fractional radiation*

	Absolute Backscatter Dose (mSV) ±SD					Percent Dose Difference-PDD (%)		
	No restoration$^{\alpha}$	Zirconia$^{\beta}$	Titanium$^{\beta}$	Lithium Disilicate$^{\beta}$		Zirconia	Titanium	Lithium Disilicate
2Gy	8.076±1.7	9.071±3.1	9.899±4.2	8.709±2.9		+12.32	+22.57	+7.83
10Gy	45.336±1.5	40.703±11.8	36.146±6.5	39.895±14.7		-10.22	-20.27	-12

$^{\alpha}$ refers to D1 (the photon dosage in only soft tissue-equivalent bolus material), and $^{\beta}$ refers to D2 (the photon dosage in the presence of a dental restoration material).

The presence of 5mm PVS in both high and medium viscosity reduced the scattered radiation from all dental materials. 5mm PVS samples provided higher dose attenuation than others. Without considering dental material, it is seen that the attenuation intensities calculated from TLD-100s ranged from 22.7 to 38,62 for 2Gy, and 10.01 to 38,87 for 10Gy fractional dosage (Table 2 and Table 3). In addition, according to the results of the study, increases in scattered doses were also observed in the presence of PVS samples.

Table 2. *Absolute scattered dose and percent dose differences in PVS presence with different dental restoration materials for 2Gy fractional radiation.*

		Absolute Backscatter Dose (mSV) ± SD			Percent Dose Differences (%)		
		Zirconia µ	Titanium µ	Lithium Disilicate µ	Zirconia	Titanium	Lithium Disilicate
High viscosity PVS							
	5 mm	6.118±0.7	6.076±1.4	6.464±1.4	-32.55	-38.62	-34.69
	10 mm	8.130±1.6	7.124±1.2	6.744±3.1	-10.37	-28.03	-31.87
	20 mm	6.272±1.7	8.103±4.5	7.249±2.1	-30.86	-18.14	-26.77
Medium viscosity PVS							
	5 mm	7.012±1.9	5.775±0.5	6.333±0.8	-22.70	-36.33	-27.28
	10 mm	6.668±2.9	7.168±3.5	14.758±6.6	-26.49	-20.98	+69.46
	20 mm	8.167±2.3	7.276±3.9	7.924±4.4	-9.97	-19.78	-9.01

µ refers to D3 (the photon dosage in the presence of a PVS around the dental restoration material at the exact precise location)

Table 3. *Absolute scattered dose and percent dose differences in the presence of PVS with different dental restoration materials for 10Gy fractional radiation*

		Absolute Backscatter Dose (mSV) ± SD			Percent Dose Differences (%)		
		Zirconia µ	Titanium µ	Lithium Disilicate µ	Zirconia	Titanium	Lithium Disilicate
High viscosity PVS							
	5 mm	24.880±5.6	32.529±7.3	28.549±7.3	-38.87	-10.01	W-28.44
	10 mm	38.890±15.6	36.233±8.4	38.288±.5	-4.46	+0.24	-4.03
	20 mm	48.850±20.9	33.480±12.6	32.677±14.2	+20.01	-7.38	-18.09
Medium viscosity PVS							
	5 mm	29.530±6.5	32.469±2.7	32.199±8.6	-27.45	-20.23	-20.89
	10 mm	36.431±15.4	40.558±19.7	34.320±5.7	-10.50	-0.36	-15.68
	20 mm	34.229±11	32.276±10.9	34.294±15	-15.91	-20.70	-15.75

µ refers to D3 (the photon dosage in the presence of a PVS around the dental restoration material at the exact precise location)

4. DISCUSSION

This study observed that contemporary prosthodontic dental materials affected dose distribution on an appropriate model for HNRT due to the backscattering effect of the materials themselves. It is demonstrated that dental material may increase the backscattered radiation for 2Gy but reduce for 10Gy fractional dose adjacent area. Authors concluded that these results were the limitation of TLD-100 dosimetry. Namely, the luminescence dosimetry related to high-sensitive LiF:Mg,Cu,P, or Al_2O_3:C has a poor response to the growing ionization density of the radiation field, such as 10 Gy, which may result in an underestimation of the dose values (16). In this study, it is decided to utilize an in-phantom TLD-100 dosimeter based on Lithium Fluoride doped with Magnesium and Titanium (LiF: Mg, Ti) to measure the secondary radiation outside the treatment area. The reason behind using the TLD-100 dosimeter was that it demonstrates close tissue equivalency, compact size, high accuracy, repeatability, and low signal fading (22). Also, it is very convenient for them to use it as an out-of-field dose detector for treatment energies up to 10 MV (23). Three TLD-100 dosimeters were used in an experimental setup to ensure stable dosimetry readings around dental materials. TLD-100 dosimeters were placed at 120 angles away from each other and in a different direction from the central beam to avoid the misleading effect of the irradiation dose for treatment over the scattered radiation measurement.

The increase varied based on the dental material: titanium (22.57%), zirconia (12.32%), and lithium disilicate (7.8%). The present study results have supported the studies conducted by Beyzadeoğlu and Akyol using a TLD dosimeter. Compared with 18% and 12.32% dose enhancement in front of Ti implant, a higher dose increase, 22.57% (17,18) was measured in this study. However, Akyol observed a maximum dose increase for (zirconia) Y-TZP implant material, contrary to our results. The differences in the results might stem from an experimental design in which they used a human mandible with a root form Ti implant. A few studies are related to the effect of lithium disilicate restoration during HNRT (2,15,19). Tso compared backscattered dose variation from different dental materials at a different distance (0,1,2,3,4, and 5mm) measured using TLD after irradiating with a 6MV photon beam (6). Their results showed that lithium disilicate had the lowest dose enhancement in all distances. The dose increase of zirconia was higher than lithium disilicate at the exact distances because of the higher physical density of zirconia. Accordingly, our results concerning dental materials are consistent with the studies mentioned above. The doses for 10Gy fractional radiation in the current study were 20.27%, 12%, and 10.22%, which attenuated after going through the dental materials for Ti, lithium disilicate, and zirconia (Y-TZP), respectively. In phantom, the electron dosage distribution is affected by the type of restoration materials used and the energy of the electron beam. As expected, the backscattering amplitude decreases when the photon beam's energy increases (20,21).

Protecting healthy tissues in irradiated head and neck cancer patients is essential. Backscattering-induced radiation enhancement has been linked to mucositis in several investigations. During radiation therapy, an adequate thickness of low-Z material (water equivalent) inserted before the tooth can protect the neighboring healthy tissues (7). In this way, the risk of acquiring oral disorders in these people can be minimized by lowering the backscatter radiation caused by dental restorations. A stent with appropriate thickness has been placed in which the tooth is put in the treatment field. It also ensures that the beam does not travel through the dental restorations, but it is not feasible. just PVS impression materials were studied in this research because it is practical and takes a few minutes to shape into a PVS stent whose consistency is excellent and fits into any place (14).

Furthermore, a few research have been conducted on PVS impression material, but in these studies, PVS used various metal additions as a shielding material. Although the PVS-metal composites, according to these investigations, are just as effective as standard shielding alloys, the metal in the composite construction caused significant backscattered radiation (12,13). Also, Feng investigated the impact of a bite block made of polyester film and putty PVS on the dosimetric variables of patients with head and neck cancer (22). Consequently, they indicated that it did not alter the dosage distribution typical of the targeted region.

This study evaluated whether PVS impression material influenced attenuating scattered radiation during HNRT, which was planned with clinical practice in mind. In addition, the effectiveness of PVS sample thickness was investigated, and their dosimetric measures were evaluated for backscattering reduction. The results show us that almost all PVS impression material attenuated the backscattered dose resulting from the dental material. Especially 5mm thickness of PVS was adequate for attenuation at both high and medium-viscosity impression materials. The conclusions of the study by Tso support our results (6). Namely, he said that a dental guard with a 5 mm spacing around all teeth might be built before radiation simulation to mitigate amplified radiation to adjacent tissues, or a stent of any thickness should at least be used to reduce the radiation exposure. Some studies have recommended that utilizing 3mm of water-density material can protect the oral mucosa against excessive doses (5,7,12,15). In this study the effect of 5, 10, and 20mm thickness of PVS was inestigated, taking into account the work of Wang declared that 4mm of a layer of PVS effectively attenuated the radiation scattered from the on metal-polysiloxane composite (13). To the best of our knowledge, no other research with the same object as this one, a study about the appropriate thickness of a stent made from only PVS impression material for HNRT, exists. Other results of our findings were that 10 and 20mm of PVS samples showed significantly less dose attenuation of both 2Gy and 10Gy irradiation except for high viscosity PVS for the 2Gy group. Increased dose attenuation might be originated from the mass density effect of PVS in 10 and 20mm groups because physical density and electron density per cm^3 is known to play roles in perturbation in dose distribution, particularly for higher energy photons (23). Consequently, the scattering of secondary electrons in PVS material itself might cause dose enhancement. Contrary to our expectation that PVS samples would decrease scattered radiation from dental materials, three measurement values of 10mm and 20mm PVS samples with different dental materials showed increases. No defined conclusion could be made about these exceptions with the experimental results. To investigate how these parameters may impact dose distribution, future studies could made. Also, there were a few limitations in the study. This study only evaluated the dose distribution along with dental material and PVS samples. Also, the experimental setup employed a simple shape to conform to the factual dose enhancement affected by the curve of a tooth, dental implant, or dental restoration. Future research might investigate alteration in tooth form, tooth density, soft tissue density, and restorative material to provide more information about dose variation.

5. CONCLUSION

This research effectively analyzed the dosage distribution for a simulated human oral cavity using real-world contemporary denture materials in this research. According to the study's findings, the presence of dental restoration material alters the scattered radiation in phantom, depending on the kind of restoration material and the intensity of the electron beam. Using polyvinyl siloxane dental impression material as a dental guard around restored teeth with contemporary dental material may help minimize irradiation of nearby normal tissues at higher doses. The guard's thickness of 5mm is adequate to provide a shielding effect against backscattered radiation regardless of the dental restorative materials and is more practical in clinical usage in terms of a stent size.

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Design of the study: Y.D., Ç.A.

Acquisition of data for the study: H.Ö.U., Y.D

Analysis of data for the study: H.Ö.U., Y.D.

Interpretation of data for the study: H.Ö.U

Drafting the manuscript: H.Ö.U, Y.D.

Revising it critically for important intellectual content: H.Ö.U, Y.D., E.B.G.A.

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