THE JOURNAL OF PROSTHETIC DENTISTRY

RESEARCH AND EDUCATION

Radiation dose enhancement associated with contemporary dental materials

Theodore V. Tso, DMD,[a] Martina Hurwitz, PhD,[b] Danielle N. Margalit, MD, MPH,[c] Sang J. Lee, DMD, MMSc,[d] Christopher L. Williams, PhD,[e] and Evan B. Rosen, DMD, MPH[f]

ABSTRACT

Statement of problem. Electron backscatter radiation from dental materials can contribute to soft tissue injury in patients undergoing head and neck radiation therapy.

Purpose. The dose enhancement from the materials used for prosthodontic restoration of the dentition has not been well quantified. This study reports the magnitude of backscatter dose from the contemporary dental materials lithium disilicate and zirconia as compared with high-noble alloy and investigates the role of a spacer material in mitigating this effect.

Material and methods. Three flat slabs of dental materials high-noble alloy, lithium disilicate, and zirconia with thicknesses of 1.5 and 3 mm were irradiated with 6-MV photons from a clinical linear accelerator. Measurements were made using a thin-window parallel-plate ionization chamber placed at 0, 1, 3, and 5 mm from the material. One millimeter of poly(methyl methacrylate) or thermoplastic material was used to cover the dental material and measure the effect on the adjacent dose enhancement.

Results. Dose enhancements between 8% and 50% were recorded adjacent to the dental restoration materials. The largest enhancements occurred for the material of the highest density, the high-noble alloy. Dose enhancement was substantially lower for lithium disilicate (8%) and zirconia (30%). The thickness of the restoration material did not significantly affect dose enhancement. The dose enhancement decreased with distance from the material, dropping to <10% for all materials at 3 mm.

Conclusions. Contemporary dental restorations enhance the backscatter dose. The presence of dental restorations may warrant the use of a stent to create separation from these materials as this can mitigate the effect. (J Prosthet Dent 2019;121:703-7)

Dental restorations containing high-Z (high atomic weight) metals and synthetic materials can enhance the adjacent radiation dose up to 2-fold.[1-3] This dose enhancement is highest adjacent to the dental restoration and may result in increased dose to the oral mucosa but dissipates with increasing distance. This effect is more pronounced as the density of the material increases[4-6] and may be attenuated by creating a space between the dental material and patient soft tissue. Intraoral radiation stents (that is, simple occlusal blocks, cotton rolls, or wax spacers and custom dental devices of varying complexity) have been suggested to achieve this attenuation to mitigate the toxicity of head and neck radiotherapy treatment.[7-11]

The introduction of tooth-colored restorative materials, which have become more common in recent years as compared with traditional metal alloy or

Materials provided by Ivoclar Vivadent AG.
Both first authors (T.V.T. and M.H.) contributed equally to the study
Both senior authors (C.L.W. and E.B.R.) contributed equally to the study
These findings were presented at the 2016 American Academy of Physicists in Medicine annual meeting in Washington DC, USA, 2016, as well as at the 2017 American College of Prosthodontics North East regional meeting in Boston, MA.
[a]Graduate student, Department of Restorative Dentistry and Biomaterial Sciences, Harvard School of Dental Medicine, Boston, Mass.
[b]Physicist, Department of Radiation Oncology, Beth Israel Deaconess Medical Center, Boston, Mass.
[c]Assistant Professor, Department of Radiation Oncology, Dana-Farber Cancer Institute, Boston, Mass.
[d]Assistant Professor, Department of Restorative Dentistry and Biomaterials Sciences, Harvard School of Dental Medicine, Boston, Mass.
[e]Instructor, Department of Radiation Oncology, Brigham and Women's Hospital, Boston, Mass; Dana-Farber Cancer Institute, Boston, Mass; and Harvard Medical School, Boston, Mass.
[f]Lecturer, Restorative Dentistry and Biomaterials Sciences, Harvard School of Dental Medicine, Boston, Mass; and Assistant Attending, Dental Service, Department of Surgery, Memorial Sloan Kettering Cancer Center, New York, NY.

Clinical Implications

High-noble alloy, lithium disilicate, and zirconia cause radiation backscatter at variable magnitudes. The use of a protective stent around dental restorations may be warranted when these materials fall within the treatment field to mitigate this effect.

metal-ceramic restorations,[12-16] has made the identification of metallic or otherwise dense dental restorations less obvious to both dental and nondental personnel. The specific dose-enhancement effect of traditional metallic dental materials has been previously reported[4,5,17]; however, few published reports have evaluated dose enhancement associated with the commonly used lithium disilicate ($Li_2Si_2O_5$) and zirconia dioxide (ZrO_2) ceramics in the context of head and neck radiation therapy.

Although the widespread adoption of intensity-modulated radiation therapy has led to more conformal dose distributions to check, it has, in some instances, resulted in an increased integral dose to the oral cavity. High-density dental materials that may not have been inside more traditional radiation fields may now contribute to mucositis in an intensity-modulated radiation therapy treatment plan.[17,18] Therefore, it remains highly relevant to study the effect of contemporary dental restoration materials as it relates to dose enhancement to minimize unnecessary dose and ultimately toxicity to the adjacent oral mucosa. The purpose of this in vitro study was to identify dose amplification of contemporary dental zirconia and lithium disilicate using high-noble alloy as a control and to model the separation needed to mitigate dose enhancement that may impact normal adjacent tissue.

MATERIAL AND METHODS

To measure the magnitude of dose enhancement adjacent to dental materials, an experimental arrangement composed of dental material specimens and tissue-equivalent polymers was developed (Fig. 1). Two specimens of each material (high-noble alloy, zirconia, and lithium disilicate) were fabricated in 20×20×1.5-mm pieces (Fig. 2). The high-noble alloy specimens (Eclipse; Dentsply Sirona) were fabricated by casting computer-aided designed and used to manufacture wax patterns (Zenotec blue; Ivoclar Vivadent AG) using the lost wax technique. The lithium disilicate specimens were fabricated by pressing C14-sized ingots to computer-aided designed wax patterns using the lost wax technique (IPS e.max Press; Ivoclar Vivadent AG). The zirconia specimens (Zenostar T; Wieland Dental) were computer-aided designed and milled in the green state and then sintered (Programat S1 1600; Ivoclar Vivadent AG). The properties of the materials comprising the specimens are listed in Table 1.

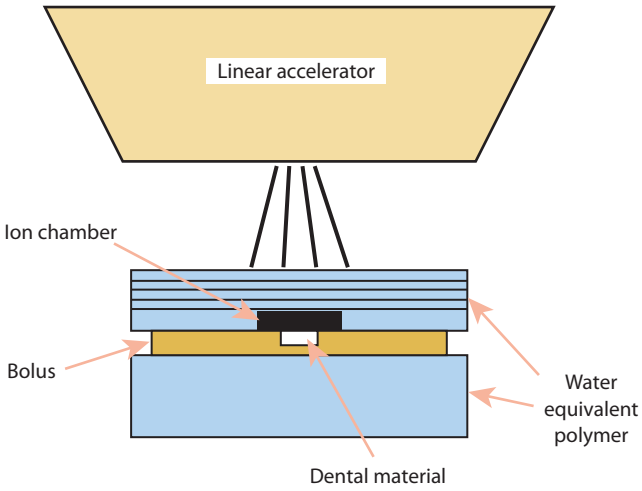

Figure 1. Diagram of experimental design (not to scale).

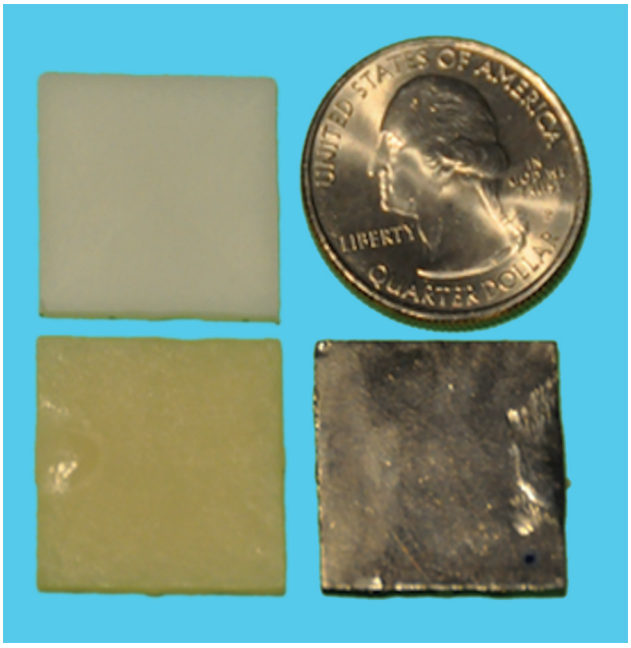

Figure 2. Material specimens of 20×20×1.5 mm: Zirconia (top left), lithium disilicate (bottom left), and high-noble alloy (bottom right). US quarter for size comparison.

The material specimens were placed into a holder composed of a bolus material (Superflab Bolus Material; CNMC Co, Inc) that was molded and cut to conform to the material specimens. Above and below the holder, prefabricated sheets of water-equivalent polymer (Plastic Water; Computerized Imaging Reference Systems, Inc) of varying thicknesses were used.

Table 1. Properties of experimental specimens

Material	Approximate Composition	Approximate Density (g/cm^3)	Effective Atomic Number (Z)
High-noble alloy[20]	52% Au, 37.5% Pd, 10% mix of Zn, Sn, In, Re	13.8	67.6
Zirconia[21]	90% ZrO_2	6.0	27.6
Lithium disilicate[22]	70% $Li_2Si_2O_5$	2.5	9.6
Enamel (for comparison)[23,24]	95% Hydroxyapatite $Ca_{10}(PO_4)_6(OH)_2$	2.8-3.0	13.7

The phantom arrangement was irradiated using a 6-MV photon beam from a clinical linear accelerator (Novalis Tx; Varian Medical Systems, Inc), a typical energy for head and neck treatments.[1] The beam was collimated to a 10×10 cm square field. The surface of the dental material was placed 100 cm from the radiation source.

The dose was measured with a thin-window parallel-plate ionization chamber (Advanced Markus Electron Chamber; PTW Freiburg GmbH). The front window of the ion chamber was placed at 0, 1, 2, 3, and 5 mm from the material specimen. At 0 mm, the ion chamber was placed directly adjacent to the material specimen. The dose measured with the material specimen in place was compared with the dose measured with no material specimen (replacing the specimen with bolus). The dose enhancement was defined as the percentage increase in measured dose with the material specimen in place. This measurement of the dose enhancement was repeated at distances of 1, 2, 3, and 5 mm by placing thin sheets of water-equivalent polymer between the dental material specimen and the ion chamber.

To measure the effect of the thickness of the dental material on dose enhancement, an additional measurement was performed with the ion chamber adjacent to 10×10×3-mm specimens of the dental materials (the thickness of the specimens was doubled by stacking two 10×10×1.5-mm specimens).

To measure the effect of placing a protective stent over the dental materials, 10×10×1 mm of poly(methyl methacrylate) (PMMA; ProBase Cold; Ivoclar Vivadent AG) was placed between the dental materials and the ion chamber. This was repeated with a thermoplastic material of the same size (10×10×1 mm) (Essix ACE Plastic; Dentsply Sirona).

Each measurement was repeated 3 times for all experimental arrangements to ensure stable ion chamber readings. The statistical uncertainty on any single reading was <0.05%. The reported results are the average of the 3 measurements.

RESULTS

The dose enhancements, as a function of the distance from the interface between the dental material and water-equivalent polymer, are presented in Figure 3 and Table 2. The largest dose enhancement of 51.9% was observed adjacent to the high-noble alloy, which was the material of the highest density. For zirconia, the enhancement adjacent to the interface was 29.9%, and for lithium disilicate, it was 7.5%. The dose enhancement decreased with distance between the ion chamber and the dental material. At 1 mm, the dose enhancements were 21.7% for high-noble alloy, 10.8% for zirconia, and 1.8% for lithium disilicate. At 3 mm, the dose enhancements were 6.4%, 2.5%, and 0.2% for the same materials.

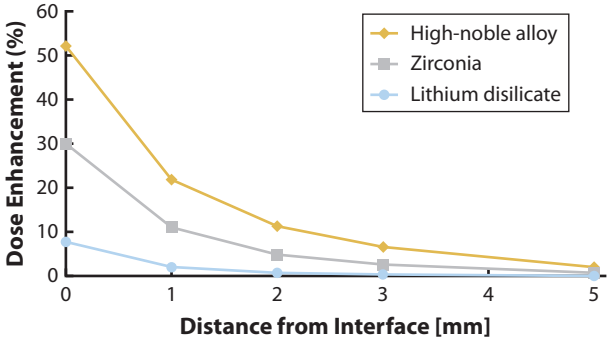

Figure 3. Dose enhancement relative to phantom composed of water-equivalent polymer as function of distance.

Table 2. Relative dose enhancement as function of distance

	Distance from Interface				
Specimen Material	0 mm	1 mm	2 mm	3 mm	5 mm
High-noble alloy (1.5 mm)	51.9%	21.7%	11.2%	6.4%	1.8%
Zirconia (1.5 mm)	29.9%	10.8%	4.8%	2.5%	0.6%
Lithium disilicate (1.5 mm)	7.5%	1.8%	0.5%	0.2%	-0.1%

The dependence of the dose enhancement on the thickness of the dental material specimen was tested by measuring dose enhancement from 1.5-mm-thick and 3.0-mm-thick specimens at 0 mm. The thickness of the specimen material did not affect the measured backscatter in this experimental arrangement (Table 3).

Dose enhancement values with the PMMA and thermoplastic stent materials in place between the dental specimen and the ion chamber and the dose enhancement values are presented in Table 4. For high-noble alloy, the enhancement was 21.7% for 1 mm of water-equivalent polymer, 18.7% for PMMA, and 22.1% for the thermoplastic material. For the other material specimens, the measured doses were similar with a 1-mm layer of each material between the dental specimen and ion chamber.

DISCUSSION

This study found that radiation dose adjacent to dental materials may be enhanced by more than 50% because of backscatter from the dental materials. This enhancement

Table 3. Relative dose enhancement using 3-mm-thick specimens

	Thickness	
Specimen Material	**1.5 mm**	**3.0 mm**
High-noble alloy (3 mm)	51.9%	52.5%
Zirconia (3 mm)	29.9%	29.6%
Lithium disilicate (3 mm)	7.5%	7.8%

Table 4. Dose enhancement with 1-mm protective stent material

	1-mm Layer Between Interface and Measurement		
Specimen Material	**Water-Equivalent Polymer**	**PMMA**	**Thermoplastic**
High-noble alloy	21.7%	18.7%	22.1%
Zirconia	10.8%	9.2%	11.1%
Lithium disilicate	1.8%	1.6%	1.8%

PMMA, poly(methyl methacrylate).

varied based on the material: metal alloy (52%), zirconia (30%), and lithium disilicate (8%). The difference between dose enhancement from 1.5-mm and 3.0-mm specimens was found to be less than 0.6% for all materials. Therefore, the thickness of a dental material in a straightforward clinical arrangement appeared to be less relevant than the composition of the material.

By creating a separation of at least 1 mm between the dental material and the point of measurement, the dose enhancement was decreased by at least 50%, providing support for the use of a separation between high-Z dental materials and oral soft tissue during radiation therapy to the head and neck. The data from the present study indicate that there is still backscatter from zirconia (upward of 29.9%) and a much smaller relative percentage of dose enhancement from lithium disilicate. Further research is needed to identify the percentage dose amplification that corresponds to clinically significant adverse effects as the dose amplification that directly correlates with the development of treatment toxicity such as mucositis is still not well defined. A separation of 5 mm from the materials tested in this study effectively eliminates dose enhancement to the surrounding tissues regardless of the underlying dental material. An intraoral radiation stent of this thickness would provide this protection.

The study had several limitations. First, the experimental arrangement used a simplified geometry to conform the specimen to the flat surface of the ion chamber. The curvature of a tooth, dental implant, or dental restoration could affect true dose enhancement, but this design was selected to allow for clarity in interpretation. Future studies could evaluate differences in tooth shape, tooth density, and soft tissue density among individuals and determine how these parameters may impact dose enhancement. In addition, the ion chamber used to measure dose delivered in radiation therapy passed through an entrance window composed of a 0.03-mm polyethylene foil before entering the sensitive volume which introduced a certain amount of error in the distance measured from the specimen. The entrance window—unavoidable when using ion chambers—is small but presents a small error in terms of dose delivery measurement. Finally, this study used only 6-MV beam energy, which is typically used for treatment of head and neck cancer. If lower beam energy is used, backscatter may differ, likely resulting in higher dose enhancement.[19] The impact of particle therapy on oral backscatter is also an area for future research.

CONCLUSIONS

Based on the findings of this in vitro study, the following conclusions were drawn:

1. Contemporary dental materials, particularly those of higher density, can amplify radiation to adjacent tissues.
2. A dental guard that creates a space of 5 mm around all teeth can be made before radiation simulation to mitigate this effect.
3. If a patient cannot tolerate a 5-mm spacer, it would be preferable to place a stent of any thickness to attenuate the radiation dose.
4. For patients unwilling or unable to undergo additional dental procedures, existing intraoral prostheses can be used or modified to serve the role of the radiation stent.
5. Ultimately, coordination with the treating radiation oncologist to accomplish the goal of mitigating treatment toxicity in an expedient manner is paramount for the management of patients in an oncology setting.

REFERENCES

1. Chin DW, Treister N, Friedland B, Cormack RA, Tishler RB, Makrigiorgos GM, et al. Effect of dental restorations and prostheses on radiotherapy dose distribution: a Monte Carlo study. J Appl Clin Med Phys 2009;10:2853.
2. Thilmann C, Adamietz IA, Ramm U, Rahn R, Mose S, Saran F, et al. In vivo dose increase in the presence of dental alloys during 60Co-gamma-ray therapy of the oral cavity. Med Dosim 1996;21:149-54.
3. Farman AG, Sharma S, George DI, Wilson D, Dodd D, Figa R, et al. Backscattering from dental restorations and splint materials during therapeutic radiation. Radiology 1985;156:523-6.
4. Farahani M, Eichmiller FC, McLaughlin WL. Measurement of absorbed dose near metal and dental material interfaces irradiated by x- and gamma-ray therapy beams. Phys Med Biol 1990;35:369-85.
5. Reitemeier B, Reitemeier G, Schmidt A, Schaal W, Blochberger P, Lehmann D, et al. Evaluation of a device for attenuation of electron release from dental restorations in a therapeutic radiation field. J Prosthet Dent 2002;87:323-7.
6. Wang RR, Pillai K, Jones PK. In vitro backscattering from implant materials during radiotherapy. J Prosthet Dent 1996;75:626-32.
7. Johnson B, Sales L, Winston A, Liao J, Laramore G, Parvathaneni U. Fabrication of customized tongue-displacing stents: considerations for use in patients receiving head and neck radiotherapy. J Am Dent Assoc 2013;144:594-600.
8. Farahani M, Eichmiller FC, McLaughlin WL. Metal-polysiloxane shields for radiation therapy of maxillo-facial tumors. Med Phys 1991;18:273-8.
9. Kawamura M, Maeda Y, Takamatsu S, Tameshige Y, Sasaki M, Asahi S, et al. The usefulness of vinyl polysiloxane dental impression material as a proton

beam stopper to save normal tissue during irradiation of the oral cavity: basic and clinical verifications. Med Phys 2013;40:081707.
10. Ikawa H, Koto M, Ebner DK, Takagi R, Hayashi K, Tsuji H, et al. A custom-made mouthpiece incorporating tongue depressors and elevators to reduce radiation-induced tongue mucositis during carbon-ion radiation therapy for head and neck cancer. Pract Radiat Oncol 2018;8:e27-31.
11. Rocha BA, Lima LMC, Paranaíba LMR, Martinez ADS, Pires MBO, de Freitas EM, et al. Intraoral stents in preventing adverse radiotherapeutic effects in lip cancer patients. Rep Pract Oncol Radiother 2017;22:450-4.
12. Christensen GJ. In-office CAD/CAM milling of restorations: the future? J Am Dent Assoc 2008;139:83-5.
13. Della Bona A, Kelly JR. The clinical success of all-ceramic restorations. J Am Dent Assoc 2008;139(Suppl):8S-13S.
14. Frazier KB, Mjor IA. The teaching of all-ceramic restorations in North Americandental schools: materials and techniques employed. J Esthet Dent 1997;9:86-93.
15. Qualtrough AJ, Mjor IA, Crisp RJ, Wilson NH. Teaching of all-ceramic restorations in central European dental schools: a survey. Eur J Dent Educ 1997;1:181-5.
16. Griggs JA. Recent advances in materials for all-ceramic restorations. Dent Clin North Am 2007;51:713-27, viii.
17. Fuller CD, Diaz I, Cavanaugh SX, Eng TY. In vivo dose perturbation effects of metallic dental alloys during head and neck irradiation with intensity modulated radiation therapy. Oral Oncol 2004;40:645-8.
18. Kim Y, Tome WA, Bal M, McNutt TR, Spies L. The impact of dental metal artifacts on head and neck IMRT dose distributions. Radiother Oncol 2006;79:198-202.
19. Klevenhagen SC, Lambert GD, Arbabi A. Backscattering in electron beam therapy for energies between 3 and 35 MeV. Phys Med Biol 1982;27:363-73.
20. Dentsply Sirona. Dentsply Ceramco Alloys [Internet]. York: Dentsply International Inc; 2011. Available from: https://www.dentsplysirona.com/content/dam/dentsply/pim/manufacturer/Prosthetics/Fixed/Alloys/Solders/Solders/Solders-vjdv4ch-pdf-en-1402. Accessed July 14, 2018.
21. Ivoclar Vivadent AG. IPS e.max ZirCAD Scientific Documentation [Internet]. Schaan: Ivoclar Vivadent AG; 2005. Available from: http://roedentallab.com/downloads/emaxZirconiaData.pdf. Accessed July 14, 2018.
22. Ivoclar Vivadent AG. IPS e.max Press Scientific Documentation [Internet]. Schaan: Ivoclar Vivadent AG; 2011. Available from: http://downloads.ivoclarvivadent.com/zoolu-website/media/document/9808/IPS+e-max+Press?_ga=2.54745515.1271079551.1531586016-829787394.1530706137. Accessed July 14, 2018.
23. Nanci A. Ten Cate's oral histology. 9th ed. St. Louis: Elsevier; 2012. p. 118.
24. Weidmann SM, Weatherell JA, Hamm SM. Variations of enamel density in sections of human teeth. Arch Oral Biol 1967;12:85-97.

Corresponding author:
Dr Evan B. Rosen
Dental Service, Department of Surgery
Memorial Sloan Kettering Cancer Center
1275 York Ave
New York, NY 10065
Email: rosene@mskcc.org

Copyright © 2018 by the Editorial Council for *The Journal of Prosthetic Dentistry.*
https://doi.org/10.1016/j.prosdent.2018.07.012