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Dosimetric evaluation of scattered and attenuated radiation due to dental restorations in head and neck radiotherapy

Mona Azizi [a,*], Ali Asghar Mowlavi [a,b], Mahdi Ghorbani [c], Behnam Azadegan [a], Fatemeh Akbari [d]

[a] Physics Department, School of Sciences, Hakim Sabzevari University, Sabzevar, Iran
[b] Associate Federation Scheme, Medical Physics Field, International Centre for Theoretical Physics (ICTP), Trieste, Italy
[c] Medical Physics Research Center, Mashhad University of Medical Sciences, Mashhad, Iran
[d] Departement of Medical Physics, Reza Radiation Oncology Center, Mashhad, Iran

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ABSTRACT

In radiotherapy of head and neck cancer, the presence of high density materials modifies photon dose distribution near these high density materials during treatment. The aim of this study is to calculate the backscatter and attenuation effects of a healthy tooth, Amalgam, Ni-Cr alloy and Ceramco on the normal tissues before and after these materials irradiated by 6 and 15 MV photon beams, respectively. All measurements were carried out in a water phantom with dimension of 50 × 50 × 50 $cm^3$with an ionization chamber detector. Two points before and four points after the dental sample were considered to score the photon dose. The depth dose on the central beam axis was explored in a water phantom for source to surface distance (SSD) of 100 cm in a 10 × 10 cm^2 field size. The percentage dose change was obtained relative to the dose in water versus depth of water, tooth, Amalgam, Ni-Cr alloy and Ceramco for the photon beams. The absolute dose (cGy) was measured by prescription of 100 cGy dose in the water phantom at depth of 2.0 and 3.1 cm for 6 and 15 MV photons, respectively. At depth of 0.6 cm, the maximum percentage dose increase was observed with values of 6.99% and 9.43%for Ni-Cr and lowest percentage dose increase of 1.49% and 2.63% are related to the healthy tooth in 6 and 15 MV photon beams, respectively. The maximum absolute dose of 95.58 cGy and 93.64 cGy were observed at depth of 0.6 cm in presence of Ni-Cr alloy for 6 and 15 MV photon beams, respectively. The presence of dental restorations can cause backscattering dose during head and neck radiation therapy. Introduction of compositions and electron density of high density materials can improve the accuracy of dosimetric calculations in treatment planning systems to deliver the relevant dose to target organ and reduce the backscattering dose in healthy tissues in the surrounding of tooth.

1. Introduction

One of important issues in radiotherapy of head and neck cancer is presence of dental restorations and implants. Among cancer patients with tumor in head and neck region, most of them have non-removable dental restorations. These high density materials cause perturbation in photon dose distribution in heterogeneous media when photon beam passes through these structures (American dental association; Committee Task Group 63, 2003; Podgorsak, 2009). During the radiotherapy, oral cavity and salivary glands are exposed to extra doses of this unwanted radiation. This dose increment increases the risk of some diseases such as osteoradionecrosis and mucositis. In this treatment, to destroy the tumors total dose of 60 Gy–70 Gy is applied that can be fractionated to several exposures. The acute and side effects of radiation therapy on healthy tissues can not be eliminated (Berger, Goldsmith, & Lewis, 1996; Reitemeier, Reitemeier, Schmidt, Schaal, & Blochberger, 2002). These effects are due to dose perturbation in head and neck radiotherapy (Hancock, Epstein, & Sadler, 2003; Nabil & Samman, 2012). This topic has been

* Corresponding author. Physics Department, School of Sciences, Hakim Sabzevari University, Sabzevar, Iran.
E-mail address: monaazizi68@gmail.com (M. Azizi).

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attended by the American Association of Physicists in Medicine (AAPM) Task Group, report No. 81, to investigate the subject of management of patients with high-*Z* materials (Reft et al., 2003).

Several authors have quantitatively studied the effect of such dental restorations or high atomic number interfaces on photon dose distributions. Chang placed oral and bone phantom under 6 MV linac photon irradiation. He reported maximum and minimum backscatter dose of 53% and 10% due to presence of metal crown alloy and ceramic metal crown, respectively (Chang, Lin, Shiau, & Chie, 2014). In another study, Shimamito investigated the dose scattering due to nine dental metals in a single-field technique, three-dimensional conformal radiation therapy (3D CRT), and intensity-modulated radiation therapy (IMRT). They placed radiochromic films on dental metals in a water phantom and irradiated them with 4 MV photon beam of Siemens medical accelerator. In the single-field technique the gold metal has the largest dose increase of 19.3% compared to the other dental metals whereas 3D CRT and IMRT had lower dose scattering than the single-field technique (Shimamoto et al., 2015). Furthermore, Catli studied the effect of pure titanium, titanium alloy, amalgam, and crown on dose distribution calculated with two methods: pencil beam convolution (PBC) algorithm and Monte Carlo simulation. A dose increase was seen due to electron backscattering in 2 cm at front of dental implant in tissue whereas Eclipse treatment planning system (TPS) did not accounted this backscattering radiation. Indeed, Eclipse underestimates the backscattered dose by the dental prostheses and overestimates the dose after these metals (Çatli, 2015). De Conto investigated 6 MV photon dose distribution due to dental restorations with Monte Carlo simulation and experimental measurement. Three samples including a healthy tooth, a tooth with Amalgam, and crown were irradiated in a clinical configuration. Results showed 23.8% backscattering dose enhancement for tooth with Amalgam (Conto, Gschwind, Martin, & Makovicka, 2014).

It should be noted the previous studies have focused on 6 MV photon dose distributions whereas some of head and neck cancerous patients are treated with 15 MV high energy photons to achieve the dose uniformity and deeper penetration. Therefore, this work focused on measurement of dose perturbations from high density materials in 6 and 15 MV medical photon beams. These commercial dental materials consist of tooth, tooth with Amalgam, tooth with Ni-Cr, and tooth with Ceramco.

2. Materials and methods

2.1. Dental samples

To evaluate photon dose distribution in presence of high density inhomogeneties in 6 and 15 MV photon beams of Siemens Primus medical linear accelerator (Siemens AG, Erlangen, Germany), three types of commercial dental materials were used. These commercial dental restorations which were considered independently in this study are a healthy tooth, tooth restorated with Amalgam, tooth filled with Ni-Cr, and tooth with Ceramco. These samples were real healthy teeth which were collected randomly from dentistry clinics then were restored with frequent dentistry restoration materials. Table 1 gives the physical densities, the compositions, the effective atomic numbers (Z_{eff}), electron density, electron density per gram, and electron density per cm^3 of tooth and various restoration materials which were used in this study. These parameters will be used for more interpretation of 6 and 15 MV photon dose distribution. Z_{eff} parameter is related to gama energy and it was calculated according to Mayneord formula (Mayneord, 1937). The dental phantom consists of the tooth filled partially with the dental restorations which were placed in the middle and two healthy teeth located in the both laterals. The dimensions of the healthy tooth are $0.8 \times 1 \times 0.8$ cm^3 which consists of 50% root and 50% dentine. For the restored teeth, almost 30% of their crown was made of commercial dental restorations such as Amalgam, Ni-Cr, and Ceramco, separately. A schematic diagram of phantom configuration is shown in Fig. 1.

Table 1
Weight fraction (%), effective atomic number, physical density (g/cm^3) and electron density (number of electrons per cm^3) for tooth (Shved and Shishkina, 2000), Amalgam (Chin et al., 2009), Ni-Cr alloy (General dentalsupply n.d.) and Ceramco (Chin et al., 2009).

	Tooth	Amalgam	Ni-Cr alloy	Ceramco
Weight fraction (%)				
H	2.66	–	–	–
Be	–	–	1.65	–
C	9.33	–	–	–
N	2.02	–	–	–
O	37.28	–	–	38.96
F	0.02	–	–	–
Na	0.28	–	–	8.32
Mg	0.96	–	–	–
Al	–	–	2.00	14.65
Si	–	–	–	15.24
P	15.50	–	–	–
Cl	0.07	–	–	–
K	0.12	–	–	7.07
Ca	31.68	–	–	–
Cr	–	–	15.00	–
Ni	–	–	75.00	–
Cu	–	11.80	–	–
Zn	0.02	1.00	–	–
Mo	–	–	5.00	–
Ag	–	69.30	–	–
Sn	–	17.90	–	15.75
Ti	–	–	1.35	–
Z_{eff}	14.7	45.83	28.14	12.08
PD	2.2	8.0	7.9	2.6
EDG	2.98×10^{23}	2.62 × 1023	2.80 × 1023	2.54×10^{23}
EDV	6.42×10^{23}	2.09 × 1024	2.21 × 1024	6.61×10^{23}

Z_{eff}: Effective atomic number; **PD**: Physical density (g/cm^3); **EDG**: Electron densityper gram(number of electrons per gram); **EDV**: Electron density per volume(number of electrons per cm^3).

2.2. In-phantom experimental measurements

Experimental measurements were performed by a Wellhofer-Scanditronixdosimetry system (Wellhofer, Uppsala, Sweden) at Reza Radiation Oncology Center (Mashhad, Iran). For in-phantom measurements, the dental phantom was placed in a water phantom (RFA-300; IBA Dosimetry GmbH, Schuarzenbruck, Germany) of $50 \times 50 \times 50$ cm^3 dimensions. To score the experimental data a Semiflex ionization chamber detector (PTW 31010 REF) with sensitive volume of 0.125 cm^3 was used which was inserted in the water phantom. To keep these three dental configurations in the water, a PMMA (Polymethyl Methacrylate) holder with 1.18 g/cm^3 density was utilized due to its close density to the water. Each dental configuration was placed in the water phantom and the distance between the water surface and top of the tooth was 1 cm. The dental configuration of interest is shown in Fig. 2. Similarly for treatment of head and neck cancer, the dose was delivered with 6 and 15 MV X-ray beams so that the *Z*-axis, was perpendicular to the middle tooth sample. This measurement was repeated in the water phantom (open field) without dental sample. The irradiation purpose was to deliver 100 cGy at depth of 2.0 cm and 3.1 cm in water phantom for the 6 and 15 MV photon beams, respectively. This amount of dose corresponds to 101 monitor units (MU) for this kind of treatment unit. The field size had 10×10 cm^2 dimensions and

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