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Technical notes

Study of dental prostheses influence in radiation therapy

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A B S T R A C T

Dental prostheses made of high density material contribute to modify dose distribution in head and neck cancer treatment. Our objective is to quantify dose perturbation due to high density inhomogeneity with experimental measurements and Monte Carlo simulations.

Firstly, measurements were carried in a phantom representing a human jaw with thermoluminescent detectors (GR200A) and EBT2 Gafchromic films in the vicinity of three samples: a healthy tooth, a tooth with amalgam and a Ni–Cr crown, irradiated in clinical configuration. Secondly, Monte Carlo simulations (BEAMnrc code) were assessed in an identical configuration.

Experimental measurements and simulation results confirm the two well-known phenomena: firstly the passage from a low density medium to a high density medium induces backscattered electrons causing a dose increase at the interface, and secondly, the passage from a high density medium to a low density medium creates a dose decrease near the interface. So, the results show a 1.4% and 23.8% backscatter dose rise and attenuation after sample of 26.7% and 10.9% respectively for tooth with amalgam and crown compared to the healthy tooth.

Although a tooth with amalgam has a density of about 12–13, the changes generated are not significant. However, the results for crown (density of 8) are very significant and the discordance observed may be due to calculation point size difference 0.8 mm and 0.25 mm respectively for TLD and Monte Carlo. The use of Monte Carlo simulations and experimental measurements provides objective evidence to evaluate treatment planning system results with metal dental prostheses.

Introduction

Head and neck cancers represent about 20% of the cancers treated by radiation therapy in our institution. Amongst these patients, most of them have non-removable dental prostheses. Two types are mainly represented: an amalgam that is a material allowing to replace a hole left by caries and a crown that repairs a deteriorated tooth or covers an implant when a tooth is missing. All materials with a density higher than the human body density (like metal) are considered as high density, contrary to air which is a low density media.

The effect of low density is widely studied especially in AAPM report no 85 [1], so air is generally correctly taken into account. For high density implants, several papers about hip prostheses exist, mainly AAPM report no 81 [2] and work from our laboratory [3,4], which propose several recommendations. For a pelvic treatment with hip prostheses despite artifacts and attenuation related to metal, beam setup can be adjusted to avoid passing through the prosthesis in order to deliver the correct dose to the target.

However, these recommendations are difficult to apply for a head and neck cancer treatment because (i) there are usually more than one or two prostheses, (ii) the resulting artifacts cover entire CT image, (iii) the target is often very close to prostheses, inside artifacts and (iv) in this small area, it is difficult to avoid prostheses (Fig. 1).

Several aspects of dental prostheses were previously investigated. Farahani et al. and Russell et al. studied doses at interfaces [5,6], teams of Nadrowitz, Beyzadeaglu and Thilmann evaluated the beam angle influence [7–9]. Thilmann et al. achieve in vivo measurements with ^{60}Co [9]. These works were done in simple conditions using a single sample by experimental measurements. A study suggests the use of cotton or water equivalent protection around teeth, like dental protection for sportsmen [10,11] but it is not easy and comfortable for patients so it is never setup in clinical.

The most recent publications use Monte Carlo methods where simulations are compared with experimental measurements

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Figure 1. A CT-slice with artifacts due to dental prostheses.

[12–15]. Palleri et al. and Spiridovich et al. [14,16] also compared Monte Carlo with commercial Pinnacle Treatment Planning System (TPS), Philips, and superposition algorithm, both showing weaknesses of these systems. On their side, Webster et al. [17] studied the efficiency of different artifact corrections on CT images on 15 patients.

In this study, we focus on the evaluation of one sample influence in a 6 MV photon beam (i) by experimental measurements using thermoluminescent detector (TLD) in homemade phantom, (ii) by Monte Carlo simulations using BEAMnrc code in which the phantom was modeled. Our goal is to compare with clinical treatment planning system (TPS) calculations performed on CT images without artifacts correction.

Materials and methods

In order to estimate the dose at interfaces, three systems are compared: experimental measurements, simulations by Monte Carlo method and treatment planning system used in clinical with a homemade phantom.

Phantom

A phantom was specially built and composed of five 12 cm × 24 cm × 1 cm-thick slabs of PMMA (Polymethyl Methacrylate), as well as three central slabs perforated in a U-shaped jaw and dental arch (see Fig. 2). Two slabs are replaced by PVDF (PolyVinyliDene Fluoride) and the last slab allows putting a sample and detectors in bolus material.

Table 1
Composition, density and effective atomic number of different materials.

Material	Composition	Density	Z_{eff} [18]
Water/tissue	H_2O/H, C, N, O	1	7.5
Bone	H, C, N, O, Mg, P, S, Ca, Zn	1.85	11.8
Tooth	H, Na, Mg, C, P, O, Ca	2.2	8.5
PMMA	Polymer	1.19	6.5
PVDF	Polymer	1.78	9
Bolus	Silicon	1.05	7.3
Amalgam	50% Hg, 30% Ag, Cu, Sn, Zn	12–13	67.4
Crown	59.5% Co, 31.5% Cr, 5% Mo, 2% Si, 1% Mn	8.8	27.1

PMMA, PVDF and bolus are, respectively, water, bone and water equivalent materials, which have a close physical density and a close effective atomic number. A medium is equivalent to another if it can reproduce a cross section and if their collision stopping powers are similar. The last column in Table 1 gives the effective atomic number of materials.

Samples

Three real tooth samples were used independently: a healthy tooth, a tooth with amalgam (the quantity of amalgam is represented in hatched area in Fig. 2) and a crown. They represent the two most frequent metallic materials.

Table 1 gives the composition, the density and the effective atomic number (Z_{eff}) of various materials used in this study. Z_{eff} was determined according to Mayneord formula [18].

One can notice from the density data, that the mean density value for a tooth is slightly greater than bone but relatively close. Therefore it is taken into account in Hounsfield unit and so in TPS. The choice is done to use the tooth as a reference.

Experimental measurements

Experimental measurements are performed using thermoluminescent detectors (TLD), GR200A type (4.5 mm in diameter and 0.8 mm thick) calibrated. The phantom permits the positioning of four TLD perpendiculars to the beam direction: one at each interface, one at 5 mm before the sample and one at 5 mm after the sample (see Fig. 3).

Simulations

The Monte Carlo simulations are achieved using the OMEGA/BEAMnrc code V4 (2009) [19,20] specific to radiotherapy. 6 MV photon beam of Clinac 2100C, VARIAN linear accelerator was modeled in BEAMnrc module to create a phase space at 90 cm of the source. The phantom described in Section 2.1 was modeled voxel by

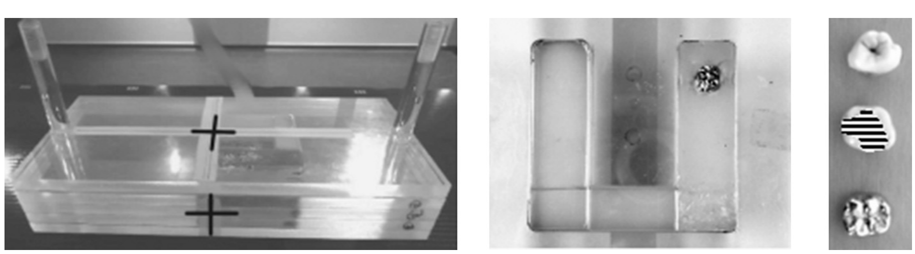

Figure 2. Global view of phantom to the left, U-shaped slab with a sample in bolus material in the middle and three samples used on the right from bottom to top: tooth, tooth with amalgam (quantity of amalgam in the tooth is represented approximately in hatched area) and crown.