Technical notes

Study of dental prostheses influence in radiation therapy

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\textbf{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.

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\textbf{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 medium.

The effect of low density is widely studied especially in AAPM report no 85\textsuperscript{[1]}, so air is generally correctly taken into account. For high density implants, several papers about hip prostheses exist, mainly AAPM report no 81\textsuperscript{[2]} and work from our laboratory\textsuperscript{[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\textsuperscript{[5,6]}, teams of Nadrowitz, Beyzadeaglu and Thilmann evaluated the beam angle influence\textsuperscript{[7–9]}. Thilmann et al. achieve in vivo measurements with \(^{60}\text{Co}\)\textsuperscript{[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\textsuperscript{[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.
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.

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 voxel.
voxel in Cartesian geometry. A material is assigned to every voxel. The peripheral voxels are 5 mm × 5 mm × 5 mm in order to obtain a gain for computation time. The voxels in the region of interest are smaller (0.25 mm × 0.25 mm × 0.25 mm) to improve the result accuracy. The cross section of amalgam and crown was created in PEGS4 module while tooth was approximated with pyrex.

The dose is delivered at the isocentre at a 6 cm depth of a phantom with a 6 MV X-ray lateral beam, perpendicular to the sample (see Fig. 3) similarly to beams used for a head and neck cancer treatment. The field has a 5 cm × 5 cm dimension in SID technique (Source Isocenter Distance of 100 cm).

The purpose is to deliver 2 Gy at the isocenter. For a homogenous water phantom configuration, this dose corresponds to 191 monitor units (MU) for this treatment device. Therefore, this value was used in all sample configurations for experimental measurements and TPS calculations.

**Irradiation conditions**

The influence of high density prostheses compared to healthy teeth is determined with three different methods: experimental measurements with TLD, Monte Carlo simulation and Pencil Beam algorithm with inhomogeneity correction are given in Table 2 for a 6 MV photon beam. The uncertainties of these methods are below 2%, 3% (2%) and 4%, respectively, for TLD, BEAMnrc with amalgam (BEAMnrc for others samples) and OMP TPS.

**Figure 4** presents the results of clinical algorithms compared to TLD for the crown. **Figure 5** shows the Monte Carlo simulations results for the three samples. **Figure 6** presents the dose of the three samples using algorithm Pencil Beam clinical with inhomogeneity correction. The results are discussed according two area of interest (i) the first area is before the sample where we search to observe the backscatter phenomenon and (ii) the second area is after the sample where the dose is attenuated.

**First interface: backscatter evaluation**

For the crown, only Monte Carlo simulations highlight backscatter of electrons with a dose increase of +23.7% compared with

**Results and discussion**

For example, photo shows amalgam orientation in the beam.

**Figure 3.** Representation of samples and measurement point dispositions in phantom (top view). The gray arrow indicates the beam orientation. For example, photo shows amalgam orientation in the beam.
tooth. The 0.25 mm dimension grid can explain this result that is not observed with TLD (0.8 mm) and TPS (5 mm). The backscatter phenomenon happens only along few micrometers and, more importantly, with high density and high photon energy [1].

For the tooth with amalgam, there are no differences with the tooth using the three methods. These results are the consequences of the sample configuration: the amalgam is surrounded by tooth so the interface with amalgam is inside the tooth and not accessible for measurement. However, the depth dose profile obtained with Monte Carlo simulations shows the backscatter inside the tooth.

These results are consistent with the works leads by Farahani, Russell and Ravikumar teams [5,6,25] who concentrated their researches on backscattered experimental measurements. They showed a dose increase up to 25%, 30%, 60% and 70%, respectively, for tooth, NiCr alloy, gold alloy and AgHg amalgam compared to polystyrene.

Second interface and beyond: attenuation evaluation

For tooth with amalgam, only Monte Carlo simulations show a sharp attenuation, this is not confirmed by other methods. This result is probably caused by a difference in the composition between the sample and the material defined in the simulation. These results must be confirmed in future study by specifying composition.

For crown, the attenuation was significant, the evaluated underdosages were 10.6%, 17.1%, 1.7% and 3.7%, respectively, for

Monte Carlo, TLD, Pencil Beam with inhomogeneity correction and Collapsed Cone with inhomogeneity correction.

We can notice on Fig. 4 that PB and CC algorithms, without inhomogeneity correction, give the same results since both computations are performed for water homogenous medium. When inhomogeneity correction was selected, CC is closer to experimental measurements (TLD) than PB. However the attenuation is underestimated by around 10.5% and 14.6% respectively for CC and PB.

Moreover, for crown and amalgam (Hg-Ag alloy), we can observe with MC method a non-negligible attenuation persistent at 2 cm after sample respectively of 4.9% and 18.1%, exactly where the target volume is.

For further studies, Monte Carlo simulation will be taken as a reference in a first approach, instead of initiating experimental measurements, which have complex setup and are time consuming. Many studies [12,16] validated BEAMnrc as a reference for radiotherapy up to iron material ($d = 7.9$).

For CT images, Fig. 7 shows the results of two delineated methods: first, the crown is delineated and a 2.4 density was attributed (blue triangle). In the second case, the crown is also delineated keeping the
supported by many studies. A proposed solution is to protect using a lateral 6 MV photon beam.

Crown. The irradiation configuration is a simplification of a head and neck cancer treatment, i.e. a lateral 6 MV photon beam.

The backscatter with high density material is observed and supported by many studies. A proposed solution is to protect using water equivalent material around teeth but it is difficult to apply in practical. Whereas the attenuation is demonstrated, the consequences on the target volume are undeveloped, and especially the artifacts on CT images used for dose planning in order to treat a cancerous tumor.

In addition to focusing on attenuation phenomenon, the goal of further study will be to compare Monte Carlo simulations and clinical planning system by reproducing head and neck cancer treatment on CT patient images with or without artifacts. This comparison will evaluate, in practical, the dose distribution modifications and if the differences on treatment are significant, while contributing to an evaluation of available methods for density reattributions.

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