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Absorbed dose simulations in near-surface regions using high dose rate Iridium-192 sources applied for brachytherapy

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HIGHLIGHTS

- A PMMA (polymethylmethacrylate) tube was used to surround the HDR Ir-192 to shield the beta particles.
- 99.2% of the absorbed doses (relative to the surface) are deposited in 5 cm depth.
- Near-surface treatments with Ir-192 HDR sources yields achievable measurements.

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ABSTRACT

Brachytherapy treatment with Iridium-192 high dose rate (HDR) sources is widely used for various tumours and it could be developed in many anatomic regions. Iridium-192 sources are inserted inside or close to the region that will be treated. Usually, the treatment is performed in prostate, gynaecological, lung, breast and oral cavity regions for a better clinical dose coverage compared with other techniques, such as, high energy photons and Cobalt-60 machines. This work will evaluate absorbed dose distributions in near-surface regions around Ir-192 HDR sources. Near-surface dose measurements are a complex task, due to the contribution of beta particles in the near-surface regions. These dose distributions should be useful for non-tumour treatments, such as keloids, and other non-intracavitary technique. For the absorbed dose distribution simulations the Monte Carlo code PENELOPE with the general code penEasy was used. Ir-192 source geometry and a Polymethylmethacrylate (PMMA) tube, for beta particles shield were modelled to yield the percentage depth dose (PDD) on a cubic water phantom. Absorbed dose simulations were realized at the central axis to yield the Ir-192 dose fall-off along central axis. The results showed that more than 99.2% of the absorbed doses (relative to the surface) are deposited in 5 cm depth but with slower rate at higher distances. Near-surface treatments with Ir-192 HDR sources yields achievable measurements and with proper clinical technique and accessories should apply as an alternative for treatment of lesions where only beta sources were used.

1. Introduction

Brachytherapy is a modality of radiotherapy using radioactive or electronic sources for treatment of several tumors or diseases, mainly intracavitary tumors (Podgorsak, 2005; Rivard et al., 2006). Brachytherapy has been used since the 19th century, but the technological evolutions aid the brachytherapy techniques improving the treatment outcomes, such as, the accuracy of source manufacture, incorporation of the image acquisition from patients (computed tomography – CT, magnetic resonance imaging – MRI and ultrasound) to dose planning and computer systems for a faster and more precise dose calculations used for patient treatment planning (Rivard et al., 2009).

Iridium-192 (Ir-192) sources are the most popular source for temporary high dose rate (HDR) applications, with 370 keV gamma average energy and 72.3 days half life is suitable for well located volumes and it minimizes the absorbed dose for distances greater than 5 cm from the region to be treated (Nath et al., 1995; Rostelato et al., 2008).

The American Association of Physicists in Medicine—AAPM has published protocols for brachytherapy sources dosimetry based in air kerma strength (S_k) and other quantities. The protocol is popularly known by TG-43. The reference distance used in this protocol is on the transverse bisector of the source at 1 cm from

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its center in water (r_0=1 cm and $\theta_0=\pi/2$) (Zeituni et al., 2012; Rivard et al., 2004). Although the TG-43 is adopted for many treatment algorithms and it is not simple to account for the absorbed dose for distances lower than 1 cm, requiring extrapolation methods that could not be so accurate to yield the absorbed dose prescription.

Studies involving the dose profile near Ir-192 sources were realized by the other groups, relating to the contribution of beta spectrum from the Ir-192. Baltas et al. evaluate the absorbed dose from the Ir-192 beta spectrum is relatively connected with the source encapsulation, the dose should be enhancement by around 50% in a 0.5 mm whether the beta dose contribution was considered (Baltas et al., 2001). Chiu-Tsao et al. (2007) published a consensus data for intravascular brachytherapy dosimetry for Ir-192, in seed and in train shapes and Massillon-J. et al. (2012) using the high spatial gel dosimetry for a Ir-192 seed also conclude the importance to consider the dose from the beta spectrum.

Although, the beta spectrum is important for near-surface absorbed dose, for superficial lesions this spectrum is not clinically efficient, due to low energy beta contamination effects on skin (erythema), different for intravascular brachytherapy (restenosis) that deals with a vessel lesion (Chiu-Tsao et al., 2007).

Keloids treatments with HDR Ir-192 brachytherapy were reported with satisfactory outcomes and with low recurrence rate (Garg et al., 2004; Arnault et al., 2009).

Absorbed doses measurements were performed by Issa et al. (2012a, 2012b) using Ge-doped fibers dosimeters and compared with Monte Carlo simulations, with distances up to 20 mm from the radioactive sources and considering the encapsulation for beta particles shielding. It was found an agreement within 3% and 1%, for Ba-133 and Co-60, respectively.

This work will evaluate the dose distribution for distances (<10 cm) around a HDR Ir-192 approximating a dose distribution "free" of beta particles shielding a HDR Ir-192 source with a water material equivalent.

2. Methodology

To obtain a free beta spectrum, it was taken into account that the maximum beta range with 670 keV, in water the range is ~2.5 mm (Baltas et al., 2001). To achieve this shield, a water material equivalent with 2.5 mm of thickness was simulated.

All simulations were performed with Monte Carlo (MC) code PENELOPE 2008 using the program PenEasy (Salvat et al., 2009). PENELOPE simulates coupled photons, electrons and positrons from 50 eV to 1 GeV with complex geometries—quadric or voxelized (Sempau et al., 2011).

All simulations were realized to obtain 1.5% (k=1) of uncertainty, so the number of histories simulated varies from each simulation. The Ir-192 gamma spectrum followed the National Nuclear Data Center (Blagin, 1998). No photon polarization was used and the Ir-192 source emission was in a 4π geometry.

The source geometry used for simulations is a Gammamed 12*i* with a cylindrical active Ir core of 0.6 mm diameter and 0.5 mm length. It was assumed that the Ir-192 is uniformly distributed on the core. The core is encapsulated with stainless steel (AISI 316L) with 0.8 mm external diameter. The cable is simulated with a 60 mm length stainless steel (AISI 304)—(Pérez-Calatayud et al., 2001).

To obtain an example of beta filter, a tube of poly methyl metahcrylate (PMMA) was used to surround the HDR Ir-192. The internal diameter and external diameter are 0.8 mm and 3.3 mm, respectively, and 0.8 mm length. These dimensions were used to represent a 2.5 mm thick beta shield. PMMA material is well-establish medium to represent water equivalence for radiation dosimetry and it is usually available for different shapes.

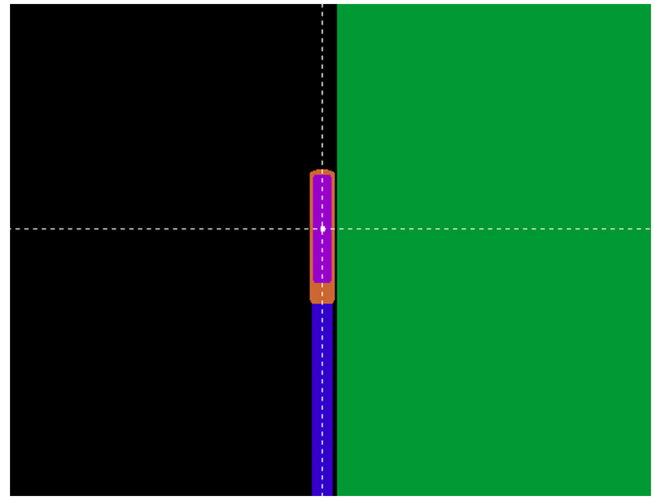

Fig. 1. Ir-192 source (center) and the water phantom (green), the beta filter as removed for source visualization and the black region represents the vacuum. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Fig. 1 shows the experimental setup with the source and water cubic phantom without the beta filter. The Ir-192 source was positioned over a cubic water phantom with 10 cm edge (1000 cm^3). To provide a full scattering conditions a large phantom (30 cm edge) should be designed, but this configuration will not represent a real condition of scattering in a patient. It was assumed that the dose contribution by the scattering radiation outer from the 10 cm range will not contribute significantly. The choice is related to the positioning of the source onto patient skin for keloid treatment (Garg et al., 2004).

To obtain the absorbed dose in water, a cubic water region with 1 cm edge (1 cm^3) was drawn, i.e., the dose profile was calculated at the central axis in water. Using water as a medium, it is not necessary to make any correction for medium heterogeneity. Only the energy deposited in this volume will be tallied. This region was shifted around the central axis until 10 cm depth. The center of Ir-192 active core is aligned with the water volume center, so that the dose distribution region should be irradiated with the scattering photon from the encapsulation and source cable.

For the dose profile simulations, 31 different distances are selected: 0.5 to 1.0 mm, with 0.1 mm step; 1.0 to 10.0 mm, with 1.0 mm step, 10.0 to 80.0 mm with 5.0 mm step and two additional distances, 95.0 and 100.0 mm.

These distances are related from the external face of the PMMA beta filter to the surface of the cubic water region.

3. Results and discussion

The results are presented as percentage depth dose (PDD) where the maximum dose is normalized to 100%. As the absolute absorbed dose depends on the source strength (S_k) and a full scattering water medium, the PDD exhibits a good way to view the dose distribution.

Fig. 2 shows the PDD for the simulated range along the central axis. The rapid dose fall-off reveals the advantage to use Ir-192 for surface lesions without compromise healthy organs. Around 13.1%, 0.8% and 0.03% of the absorbed dose is deposited in along 1, 5 and 10 cm water depth, respectively.

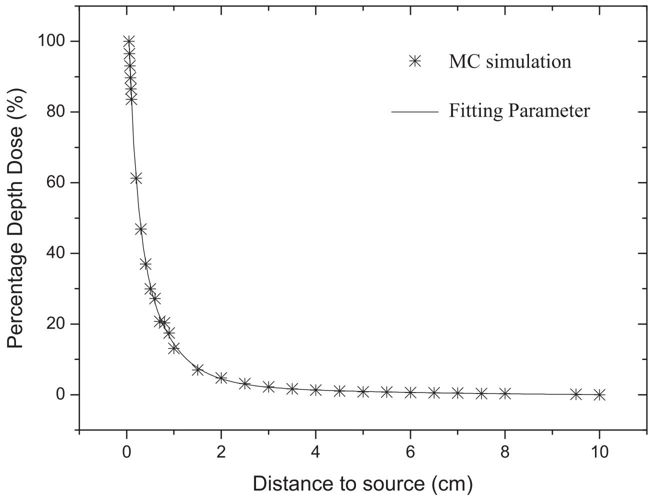

Fig. 2. Percentage dose distribution versus distance to source (cm).

The mathematical model for this PDD is showed by Eq. (1), where an exponential fitting equation (R^2=0.9996) from the simulated was obtained.

$$\mathrm{PDD}(\%) = -0.38 + 4.04 \times e^{(-(x-0.04)/4.32)} + 52.03 \times e^{(-(x-0.04)/0.63)} + 46.52 \times e^{(-(x-0.04)/0.15)} \quad (1)$$

where x is the range in centimeters along the central axis to the surface of the cubic water region.

For a clinically point of view, the results suggest that the absorbed dose deposition is entirely delivered on the surface and not contribute to dose contamination for radiosensitive regions. This suggests the use of HDR Ir-192 sources for lesions on the surface skin. The PMMA filter (for beta particle shield) may be used as an applicator for skin-surface HDR treatment, optimizing the dose distribution around the lesion and avoiding the contamination caused by the low energy beta particles.

Experimental measurements with accurate dosimeters and the simulation of heterogeneities, such as bone and adipose tissue, should be investigated for more realistic clinical conditions.

4. Conclusions

The HDR Ir-192 dose distribution on a water phantom was simulated with the MC code PENELOPE (program PenEasy). To avoid the dose contribution of beta particles, a PMMA tube was designed to provide shielding to these particles. Simulation results shown that about 99.2% of the dose profile is deposited in the 5 cm range and the dose contribution for regions outer this range it is not expressive. More realistic results, adding heterogeneities, for example, should improve the results obtained in this work.

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