Effects of different volumes of inhomogeneous medium to the radial dose and anisotropy functions in HDR brachytherapy

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Abstract. The aim of this study is to study the effects of non–homogenous region closer to the HDR Brachytherapy source. Radial widths of 1, 3 and 5 cm of an inhomogeneous cylindrical area filled with bone and lung tissue in a water phantom are modelled in this study. The effects of this inhomogeneity to the \( g(r) \) and \( F(r,\theta) \) of Nucletron \(^{192}\)Ir microSelectron HDR source are assessed. The results show that the assumption of homogeneous water leads to underestimation of the bone dose by the treatment planning system. Meanwhile, overestimation of the dose is observed in the surrounding area. A relative difference of up to 19% is calculated for the largest bone volume. Contrast results are observed for the lung inhomogeneity model. A relative difference of up to 12% is observed in the lung dose. The presence of inhomogeneous region in the water phantom affects the anisotropy function; at a radial distance greater than 5 cm. Our results indicate that the presence of bone and lung inside the water phantom affect the \( g(r) \) and \( F(r,\theta) \) in HDR brachytherapy. The degree of the effects depends on the material, position and volume of the inhomogeneity area.

1. Introduction

HDR brachytherapy is a method designed to deliver maximal dose to the tumor, while keeping the minimum dose to the surrounding healthy tissues. In clinical practice, the dose distribution in the area near to the brachytherapy source is planned and monitored using a treatment planning system (TPS) which is currently based on the recommendation by the TG-43 group [1, 2, 3]. The calculations were made based on the assumption of homogeneous water. The dose distribution around the source (due to the inhomogeneity of the medium) was previously obtained from measurement and the Monte Carlo simulation [4]. The main purpose of this study is to calculate the dose distribution for the Nucletron \(^{192}\)Ir microSelectron HDR source using MCNP5 code. With the consideration that a human body is composed of a mixture of materials, the effects of this heterogeneous medium are investigated. The effects of non-homogeneous regions close to the HDR brachytherapy source is the main objective of this study.

2. Materials and Methods

2.1. Modelling the source
This study examined the effects of inhomogeneous medium in HDR brachytherapy using MCNP5 code developed by Los Alamos National Laboratory (Los Alamos National Laboratory, Los Alamos, NM). The Nucletron $^{192}$Ir microSelectron HDR source (HDR-v2, Nucletron Inc., The Netherlands) with material density of 22.56 g cm$^{-3}$, active length 3.5 mm and diameter of 0.6 mm was modelled. The source is encapsulated in a 1.1 mm diameter stainless-steel cover ($\rho=8.027$ g cm$^{-3}$). A 5 mm steel cable ($\rho=4.81$ g cm$^{-3}$) extended from the outer steel cover on the proximal side of the active source was also modelled. The energy spectrum of $^{192}$Ir was obtained from NuDat Database [5]. The beta spectrum was excluded due to the insignificant contribution to the dose rate at a distance greater than 1 mm [6].

The data was scored using F6 tally of a grid system having 0.5 mm height and diameter cylindrical rings concentric to the longitudinal axis of the source. The position of the ring is set at a radial distance ($r$) of 0.5 to 14 cm. In each calculation, the scoring grid was fixed at the centre of the source active length. The F6 tally gives the track length estimates of energy deposition (in MeV/g). Multiplication of the output with the tally multiplier (FM) card of $1.6 \times 10^{-10}$ gives the energy deposition in a unit of Gy. To speed up the calculation, photon cut-off of 10 keV and 100 cm radius simulation boundary was defined to limit the calculation. Total number history was $5 \times 10^7$, to assure a reliable confidence interval of less than 0.1.

2.2. Heterogeneity Model

With the consideration that the human body is not uniform, we modelled an inhomogeneity area filled with bone and lung materials in our MCNP5 simulation. The influence of phantom inhomogeneity to the $g(r)$ and $F(r,\theta)$ was investigated in this study. The inhomogeneity area was defined as a cylindrical ring with a height of 30 cm and radial width of 1, 3 and 5 cm. The distance of the source to the inhomogeneity area was set to 10 mm (Figure 1).

![Figure 1](image-url). The experimental setup defined using MCNP5 for the inhomogeneity model. The dashed-line box is the scoring cells tally.

3. Results and Discussion

3.1. Radial Dose Function, $g(r)$

The $g(r)$ for $^{192}$Ir microSelectron HDR sources in water, bone and lung material are presented in the figures below. Figure 2 (a) and Figure 3(a) present the $g(r)$ of the inhomogeneous phantom that consists of bone and lung material in a water phantom. The difference among the models were noted. The relative difference of the dose calculated by our model to the TG-43 formalism is best presented by the dose ratio. The dose ratio calculated for inhomogeneous bone and lung in a water phantom to the dose in homogeneous water are shown in Figure 2(b) and Figure 3(b).
The high density of bone leads to greater scattering and attenuation inside bone material and thus lowered the dose. Hence, the dose was initially increased and exceeding the water dose inside the bone area. Beyond the inhomogeneity area, the dose started to decrease and eventually became uniform. The maximum differences of 19.41% and 77.12% were calculated between our inhomogeneous model to the homogeneous water and bone phantom, respectively. The results imply that the assumption of homogeneous water phantom leads to the underestimation of the bone dose and overestimation of the dose to the region surrounding the bone. Meanwhile, slightly different results were observed in lung inhomogeneity model. The presence of lung material caused the overestimation of the dose by TPS only at the initial half of the lung region. Beyond that, the lung dose would be underestimated by the TPS (maximum relative difference of 10.65%). Similar findings to the bone inhomogeneity was observed beyond the lung region. Consideration of 1 cm width of lung inside a water phantom in our inhomogeneous model yielded no significant dose difference to the homogeneous water phantom (maximum relative difference of 3%). However, the relative difference is more significant as the lung width increases (maximum difference of 12%).
3.2. Anisotropy Function, $F(r, \theta)$

The independent relationship between the radial distance and $F(r, \theta)$ has been discussed by Wu et al. Introduction of bone inhomogeneity area (width 1cm) does not affect the $F(r, \theta)$ at radial distance $r < 5$cm.

Figure 4. $F(r,\theta)$ calculated by MCNP5 code for the $^{192}$Ir microSelectron HDR source centred in an inhomogeneous bone and lung in a water phantom

The data showed that $F(r,\theta)$ was affected by the presence of the inhomogeneous region inside the water phantom. The effect is more acknowledged at $r > 5$ cm, whereby the variation of dose as a function of the polar angle around the source is more significantly observable. These variations were observed for all inhomogeneous models examined in this study. At $r < 5$ cm, $F(r,\theta)$ closer to 1 was observed in the inhomogeneous bone model as compared to the inhomogeneous lung model. The higher $F(r,\theta)$ for bone is due to the higher scattered components in the medium. In the presence of inhomogeneous media, at $r > 5$ cm, $F(r,\theta)$ for both bone and lung inhomogeneous in a water phantom are not comparable. As a conclusion, the presence of inhomogeneous medium in a water phantom affect the $F(r,\theta)$ at $r > 5$ cm.

4. Conclusions

As a conclusion, our results indicate that the presence of bone and lung inside the water phantom affect the $g(r)$ and $F(r,\theta)$ in HDR brachytherapy. The relative difference up to 19% was calculated for the largest bone volume and the relative difference up to 12% was observed in the lung inhomogeneity dose. The presence of inhomogeneous region in the water phantom affects the anisotropy function; at a radial distance greater than 5 cm.

5. References

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