Determination of the tissue inhomogeneity correction in high dose rate Brachytherapy for Iridium-192 source

Barlanka Ravikumar, S. Lakshminarayana[1]

Department of Radiotherapy, Government General Hospital, Kakinada, [1]Department of Nuclear Physics, Andhra University, Visakhapatnam, Andhra Pradesh, India

ABSTRACT

In Brachytherapy treatment planning, the effects of tissue heterogeneities are commonly neglected due to lack of accurate, general and fast three-dimensional (3D) dose-computational algorithms. In performing dose calculations, it is assumed that the tumor and surrounding tissues constitute a uniform, homogeneous medium equivalent to water. In the recent past, three-dimensional computed tomography (3D-CT) based treatment planning for Brachytherapy applications has been popularly adopted. However, most of the current commercially available planning systems do not provide the heterogeneity corrections for Brachytherapy dosimetry. In the present study, we have measured and quantified the impact of inhomogeneity caused by different tissues with a 0.015 cc ion chamber. Measurements were carried out in wax phantom which was employed to measure the heterogeneity. Iridium-192 (^{192}Ir) source from high dose rate (HDR) Brachytherapy machine was used as the radiation source. The reduction of dose due to tissue inhomogeneity was measured as the ratio of dose measured with different types of inhomogeneity (bone, spleen, liver, muscle and lung) to dose measured with homogeneous medium for different distances. It was observed that different tissues attenuate differently, with bone tissue showing maximum attenuation value and lung tissue resulting minimum value and rest of the tissues giving values lying in between those of bone and lung. It was also found that inhomogeneity at short distance is considerably more than that at larger distances.

Key words: Brachytherapy, dosimetry, inhomogeneity, Iridium-192 source

Introduction

Brachytherapy is a form of radiotherapy in which small, sealed radioactive sources are placed inside or near the tissue to be irradiated. With this form of treatment, a high dose can locally be delivered to the small tumor volume, with a rapid dose fall-off in the surrounding healthy tissues as a result of the inverse square law. In contrast to external beam radiotherapy (EBRT), in which high-energy X-rays are directed at the tumor from outside the body, Brachytherapy involves the precise placement of radiation source directly at the site of the cancerous tumor.

A key feature of Brachytherapy is that the irradiation only affects a very localized area around the radiation sources. Exposure to radiation of healthy tissues farther away from the sources is therefore reduced. In addition, if the patient moves or if there is any movement of the tumor within the body during treatment, the radiation sources retain their correct position relative to the tumor. These characteristics of Brachytherapy provide advantages over EBRT. The tumor can be treated with very high doses of localized radiation, whilst reducing the probability of unnecessary damage to the surrounding healthy tissues.

While calculating dose at a point in high dose rate (HDR) Brachytherapy, homogeneous water medium is assumed.[1] But, in practice, human body is not homogenous. It consists of different types of tissues like bone, liver, lung, spleen, muscle, air cavities, etc. (in between source and the point of interest). As such, the final isodose distribution is affected by the inhomogeneity around the source. Recently, three-dimensional computed tomography (3D-CT) based treatment planning for Brachytherapy applications has been popularly adopted as it shows more realistic

Address for correspondence:
Mr. Barlanka Ravikumar,
Department of Radiotherapy, Government General Hospital,
Kakinada – 53 3001, Andhra Pradesh, India.
E-mail: ravigghkkd@gmail.com

dosimetric outcome on patient anatomy. However, very few studies aimed to study the impact of tissue inhomogeneity in Brachytherapy.[2-4]

Most of the current commercially available planning systems do not provide the heterogeneity corrections for Brachytherapy dosimetry[5-7] for quantifying the effect of inhomogeneity raised[2-4] due to different types of tissues.

The present work was carried out to quantify the impact of inhomogeneity caused by different tissues for HDR Brachytherapy treatment with Iridium-192 (^{192}Ir) source. The data could be potentially helpful for developing future Brachytherapy dose calculation formalisms.

Materials and Methods

Inhomogeneity measurements were carried out in wax phantom[8,9] (30 cm · 30 cm · 15 cm) with different types of tissues, using Micro Selectron HDR ^{192}Ir source (Nucletron corporation The Netherlands) Brachytherapy machine installed in the Department of Radiotherapy. This machine also serves as the basis for calculation and measurements. We chose five different types of tissues, i.e. bone, spleen, liver, muscle and lung,[10] such that electron densities vary from $4.8 \cdot 10^{23}$ to $0.5 \cdot 10^{23}$ per cc. Fresh human tissues were collected from the Department of Forensic Medicine. These tissues were processed and cut to the required dimensions. Doses at different distances (4 cm, 6 cm, 8 cm and 9.9 cm) were calculated by Plato planning system. These were also cross-checked by manual calculations at the center of the detector point. Treatment time/dwell time was also calculated and transported to Treatment Control Station (TCS) of HDR Brachytherapy machine. Both the homogenous wax medium and the inhomogeneous tissue were irradiated for this same dwell time. A 0.015cc ion chamber Physikalisch Technische Wertstatten (PTW make)[11] was used to measure the dose, and four flexible catheters were embedded in wax phantom at distances 4 cm, 6 cm, 8 cm and 9.9 cm from the center of the ion chamber. While placing flexible catheters at different distances, utmost care was maintained as the dose is dependent upon distance. All the catheters were placed in pre-measured and cut grooves and sealed with wax so that they were immobilized. The same catheters were used throughout our experiments and the inhomogeneity due to these catheters was not taken into account. ^{192}Ir source from HDR machine was allowed to dwell at a point such that the center of the chamber, and the center and transverse axis of the source[12-14] were collinear. A 2 cm 2 cm· 2 cm hole/slot was made in the wax phantom between the ion chamber and source dwell point to accommodate tissues of different thicknesses (0.5 cm, 1.0 cm, 1.5 cm and 2.0 cm). The experimental set-up is depicted in [Figures 1,2].

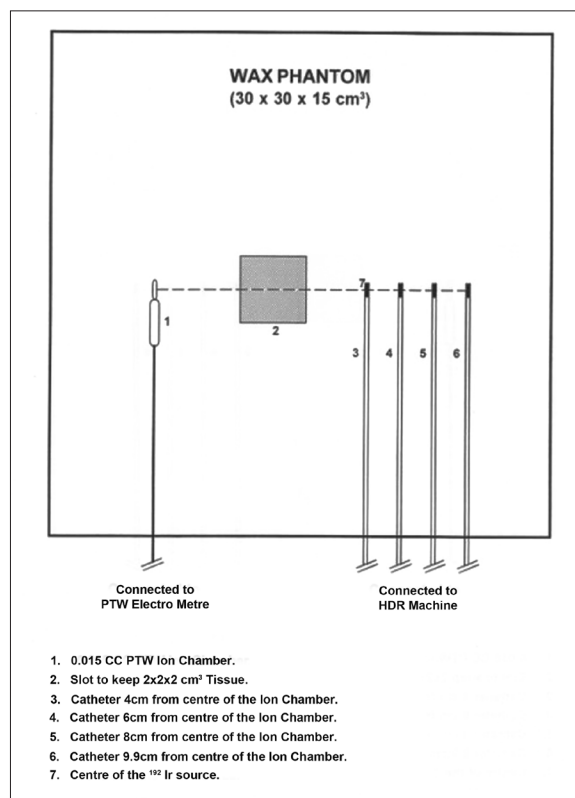The 0.015cc ion chamber was coupled to PTW

Figure 1: Schematic diagram of the experimental set-up

Figure 2: Pictorial view of the micro HDR connected with wax phantom and 0.015cc PTW ion chamber

Unidos-E electrometer to record doses and was kept in dose accumulation mode is shown in Figure 3. The instrument was allowed to stabilize before taking the readings. The machine was switched on and the readings (dose measured in terms of charge in picocoulombs) were noted down for the homogeneous medium by keeping 2-cm-thick wax block made up of same material as that of the wax phantom in the slot. After noting down the dose values, homogeneous medium, i.e. the 2-cm-thick wax block was removed. Subsequently, 0.5 cm, 1.0 cm, 1.5 cm and 2 cm thick bone, spleen, liver, muscle and lung tissues were kept in the same pre-cut slot one after the other and readings were taken for different distances. While using the tissues of thickness less than 2 cm, the vacant slot was filled with wax. Tissue homogeneity

Figure 3: Shows the Treatment control station of HDR and PTW electrometer

was measured as the ratio of dose measured with inhomogeneous medium (bone, spleen, liver, muscle and lung tissues) to the dose measured with homogeneous medium for a given distance.

The tissue homogeneity in terms of dose reduction is given by the equation:

$$\% \text{ Tissue homogeneity } (T_H) = \frac{\text{Dose } D_T \text{ with different tissue material}}{\text{Dose } D_H \text{ with homogeneous medium}} \times 100$$

Results and Discussion

In the present experiment, we tried to establish the relation between percentage homogeneity and the distance from the source for different tissues of various thicknesses. The experimental results are given in [Tables 1–5] for different tissues. They give the variation of the percentage homogeneity with distance from source for tissues of different thicknesses. The variation of homogeneity is also shown graphically in [Figures 4–8]. The absorbed dose at the point of interest is as a result of the primary beam that passes through the tissue and the scattering components from the tissue and the homogeneous phantom. At short distances from the source, the dose at the point of measurement is predominantly due to primary beam than the scattered contribution. On the other hand, at larger distance, it is mainly due to scattering component.

In the present investigation, bone tissue shows maximum dose reduction at 4 cm distance from the source for a tissue of 2-cm thickness and minimum value at a distance of 9.9 cm for 0.5-cm-thick bone tissue. The percentage homogeneity increases linearly with distance from the source. We also observe that the percentage inhomogeneity increases linearly with the thickness of the tissue. This can be attributed to the presence of high Z[15,16] elements in

Table 1: Variation of % homogeneity as a function of distance from source for bone tissues of different thicknesses

Thickness of bone tissue (cm)	% Homogeneity Distance from source in cm			
	4	6	8	9.9
0.5	95.78	96.371	97.054	97.629
1.0	92.276	92.9559	93.577	94.257
1.5	89.824	90.456	90.618	91.204
2.0	87.373	87.456	87.714	87.872

Table 2: Variation of % homogeneity as a function of distance from source for spleen tissues of different thicknesses

Thickness of spleen tissue (cm)	% Homogeneity Distance from source in cm			
	4	6	8	9.9
0.5	98.87	99.35	99.887	100.2
1.0	98.125	98.51	99.12	99.6
1.5	97.35	97.8	98.35	98.75
2.0	96.66	97.14	97.54	97.814

Table 3: Variation of % homogeneity as a function of distance from source for liver tissues of different thicknesses

Thickness of liver tissue (cm)	% Homogeneity Distance from source in cm			
	4	6	8	9.9
0.5	99.201	99.4382	99.813	100.25
1.0	98.52	98.9412	99.370	99.75
1.5	97.75	98.251	98.656	98.17
2.0	97.1	97.5	97.878	97.355

Table 4: Variation of % homogeneity as a function of distance from source for muscle tissues of different thicknesses

Thickness of muscle tissue (cm)	% Homogeneity Distance from source in cm			
	4	6	8	9.9
0.5	99.37	99.88	100.35	100.78
1.0	98.75	99.25	99.75	100.25
1.5	98.10	98.67	99.125	99.58
2.0	97.3	97.75	98.3	98.80

Tables 5: Variation of % homogeneity as a function of distance from source for lung tissues of different thicknesses

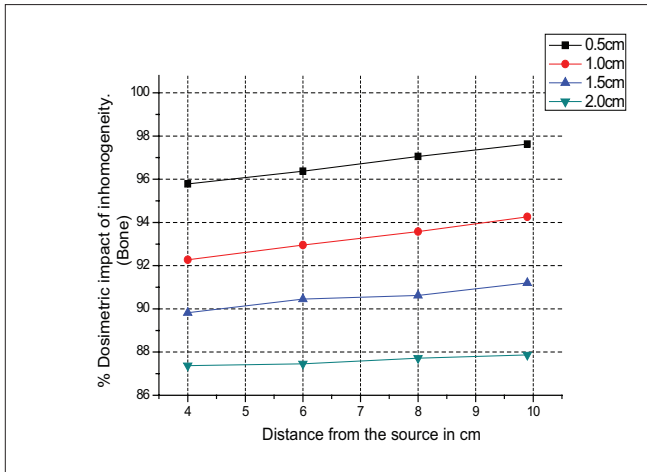| Thickness of lung tissue (cm)	% Homogeneity Distance from source in cm			
	4	6	8	9.9
0.5	99.3	99.75	100.1	100.35
1.0	100.6024	101.0536	100.4273	101.6166
1.5	101.85	102.25	102.6	102.85
2.0	103.1	103.5	103.85	104.25

Figure 4: % Dosimetric impact of inhomogeneity as a function of the distance from the source for bone tissue
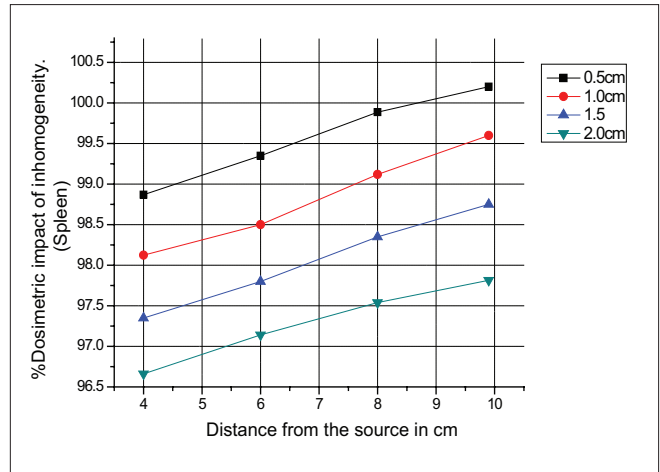

Figure 5: % Dosimetric impact of inhomogeneity as a function of the distance from the source for spleen tissue
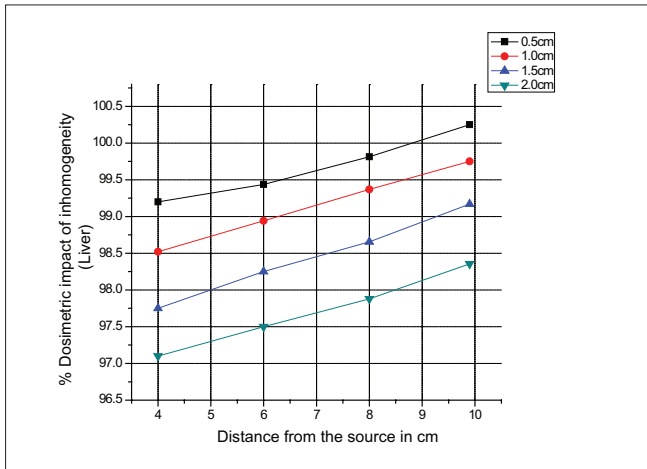

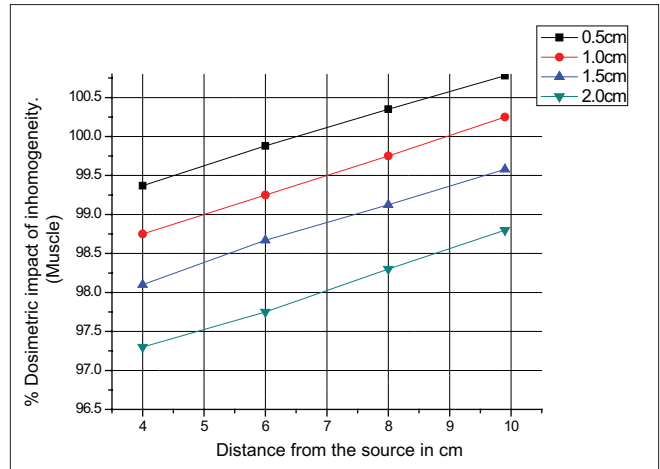**Figure 6: % Dosimetric impact of inhomogeneity as a function of the distance from the source for liver tissue**

Figure 7: % Dosimetric impact of inhomogeneity as a function of the distance from the source for muscle tissue
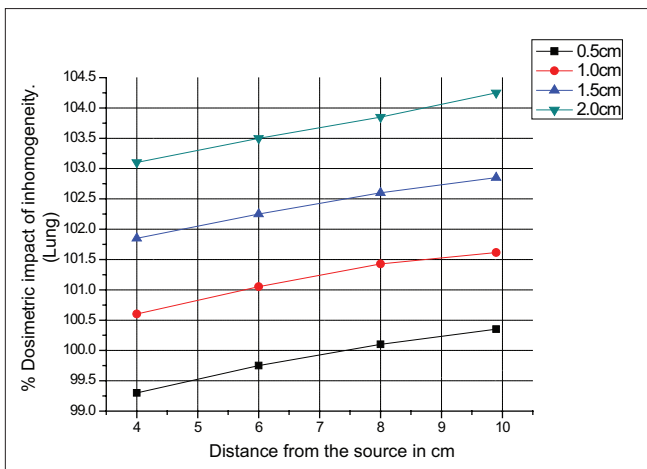

Figure 8: % Dosimetric impact of inhomogeneity as a function of the distance from the source for lung tissue

bone tissue and also its large physical density and electron density values[17] compared to the constitution of other tissues.

Spleen tissue results in lesser inhomogeneity compared to bone, but gives distinctly higher values than those of liver and muscle tissues. This is more significant for increasing thickness. It is also observed that the percentage homogeneity decreases linearly with thickness of the tissue.

Liver and muscle tissue show similar behavior as the electron densities and physical densities of liver and muscle are nearly equal.[17] The dose reductions are more significant for large tissue thickness at shorter distances from the source.

Lung tissue shows a behavior contrary to other tissues. The homogeneity increases with increasing tissue thickness for all distances from the source. This behavior can be understood as the lung is porous and filled with air. Its physical density varies between 0.2 and 0.5 gm/cm^3 during inhalation and exhalation, respectively, taking density of water as 1 gm/cm^3.[17]

Conclusions

The impact of inhomogeneity caused by different tissues has been measured. It is clear that different tissues attenuate to different extents. Bone tissue shows the maximum inhomogeneity and lung tissue shows the minimum value. Rest of the tissues give values of inhomogeneity lying in between those of bone and lung. It is also observed that inhomogeneity at short distances is considerably more than that at larger distances. The percentage homogeneity increases linearly with the distance from the source. The percentage inhomogeneity increases linearly with the thickness of the tissue. So, while calculating dose at a point, it is necessary to incorporate heterogeneity to arrive at correct dose distribution without cold or hot points.

Acknowledgments

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