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Dosimetric study of Image Guided Brachytherapy for cervix carcinoma treatment at Komfo Anokye Teaching Hospital (KATH) Using an Ionization Chamber

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Abstract

In 2D brachytherapy treatment, the lack of spatial information and low visualization of the extent of tumour, applicators in 3D and Organs at Risk (OAR) volumes results in suboptimal application technique planning and insufficient dose coverage to large tumours, which is a limitation at KATH. A water phantom was constructed for measurement of air kerma strength and dose distribution the brachytherapy sources using an ion chamber. Both 2D and 3D imaging modalities, X-ray and CT, were used and compared, including treatment planning procedures of 2D LDR and 3D IGBT. S_K (air kerma strength) for the three sources labelled V1, U3 and V5 at 2cm from the applicators were 6.839 x 10^{-12} $Gycm^2h^{-1}$, 2.043 x 10^{-11} $Gycm^2h^{-1}$ and 4.336 x 10^{-11} $Gycm^2h^{-1}$ respectively and the dose distribution measured at 2 cm from the fletcher applicators' left, top, and right directions over a 300-second period were 5.052 x 10^{-5} Gy, 2.471 x 10^{-5} Gy, and 6.133 x 10^{-5} Gy. In conclusion, Image Guided Brachytherapy is observed to high conformal dose coverage at point A or a 2cm distance from the applicators verifying the Manchester point A protocol.

Keywords

Image guided Brachytherapy, Air kerma strength, phantom, dose distribution, Dose

1. Introduction

Clinical brachytherapy (BT) involves inserting an applicator close to or into a targeted tumour (site) in which radioactive sources (^{192}Ir, ^{137}Cs, ^{60}Co) can be set in. Cervical cancer is the second most common diagnosed female disease and is more prevalent in developing countries. (4) Radiation therapy is critical in cervical cancer treatment and when combined with external beam radiation therapy, brachytherapy has been shown to improve local control and survival. (6). With the increased use of image-guided adaptive brachytherapy for cervical carcinoma, brachytherapy treatment planning has become increasingly personalized. Two-dimensional Low dose rate (LDR) brachytherapy has been the approach used by the Komfo Anokye Teaching Hospital (KATH) for cervix carcinoma boost. The treatment design is based on a small number of points determined from the patient's 2D planar images which gives inadequate spatial information of the tumour and OAR volumes and the inability to visualize the extent of the tumour and applicators in 3D. This may result in a suboptimal application technique with inadequate dose coverage to large tumours. This planning technique is executed by the prescription of the radiation dose to a geometrical point A while Image Guided Brachytherapy utilizes CT or MR imaging instead of 2D orthogonal radiographs, and dosage is prescribed to target volumes rather than points of reference, as is with 2D brachytherapy. Recent research has demonstrated that 3D-High Dose Rate (HDR) BT is effective in patients following external beam radiotherapy treatment emphasizing on the fact that in comparison to 2D-HDR-BT, this image-guided 3D HDR-BT can deliver a high conformal dosage and more precise distributions.[1] To verify this statement this study was, hence, conducted and also to determine whether the Manchester protocol delivering dose to points A is applicable in 3D-HDR-RT.

2. Methodology

A water phantom representing the female pelvis was constructed for data collection using the dimension of 40 cm x 40 cm to cover all sizes of women. A sketch of the prototype and image of the completed phantom is seen in **Figure 1** and **Figure 2** respectively.

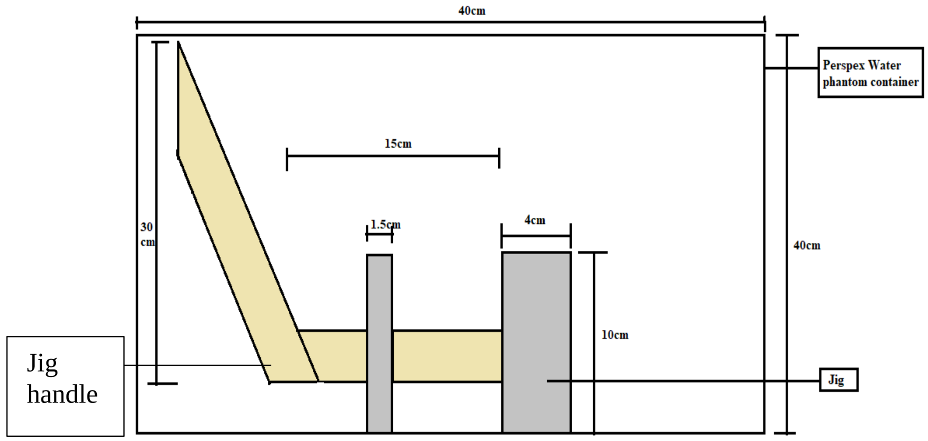

Figure 1. Side view of constructed Perspex jig with dimensions in the Perspex water phantom container where fletcher applicators are inserted into the thicker ash part of the structure labelled jig.

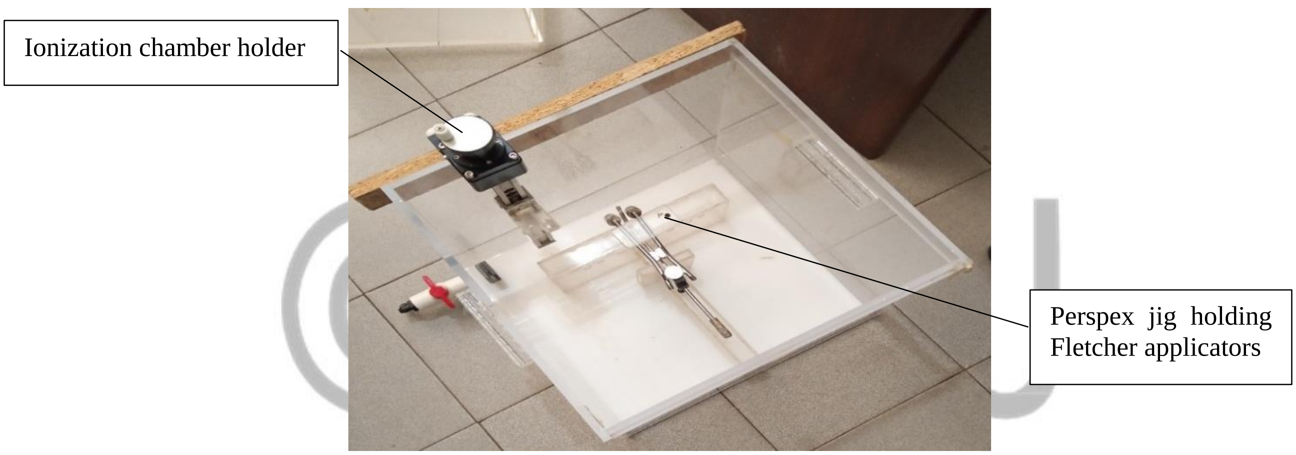

Figure 2. Image of Perspex of jig for water phantom used to hold applicators and the ionization camber holder.

An ion chamber was used for data collection in this study. A measuring assembly including an electrometer for the measurements of current or charge and a power supply for the ionization chamber's polarizing voltage. (PTW 31010). Five successive readings were taken and averaged for typical distances of 2 cm, 5 cm and 7 cm from the centre of the Cs-137 sources in all three applicators combined and the centre of the ion chamber in three different directions.

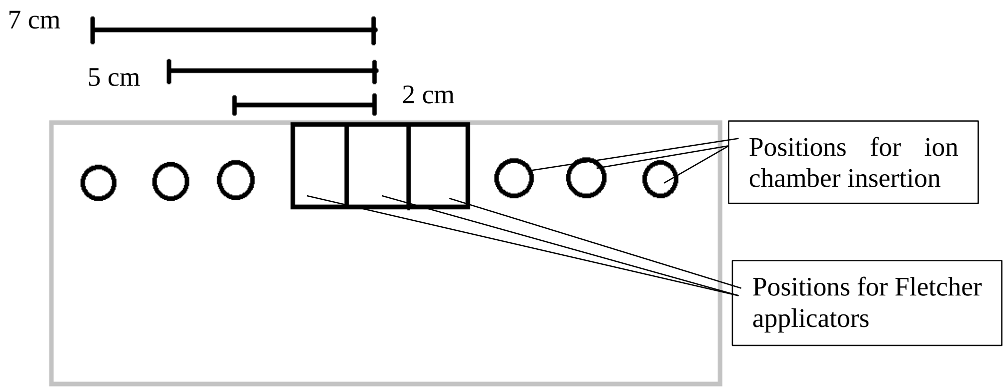

Figure 3. A sketch of the Perspex jig showing positions for the insertion of fletcher applicators and ionization chambers and the distances from which measurement of dose distribution is taken.

The measurements were corrected for temperature and pressure. These distances were considered with the Manchester system for verification of prescription to point A as reference.[2] Point A, is 2 cm lateral to the cervical canal and 2 cm superior to the cervical os. Point B is defined as 3 cm laterally from point A without displacement of the central canal. Point A moves with the canal if the tandem moves it, but 5 cm from the midline is the fixed measurement of point B. The 2D LDR planning was done with manual calculation of magnification of the image of the tandem and ovoids and the delineation of point A as well as rectum and bladder on the radiograph. This information was then digitized and transferred to the Treatment Planning system (TPS) for the dose calculation. In 3D planning, a CT image of the phantom was imported an into the TPS, where OARS and a Planning Target Volume (PTV) were contoured and the dose calculation done. The 2D and 3D planning and images of the phantom were compared. The 2D and 3D images of the applicators is seen below in **Figure 3** and **Figure 4** respectively.

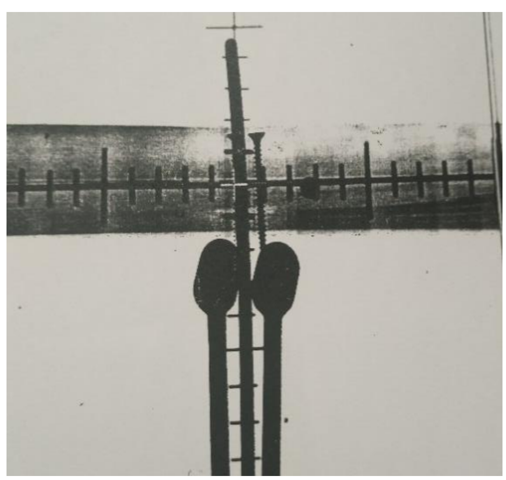

Figure 4. 2D X-ray images of anterior view of applicators in water phantom.

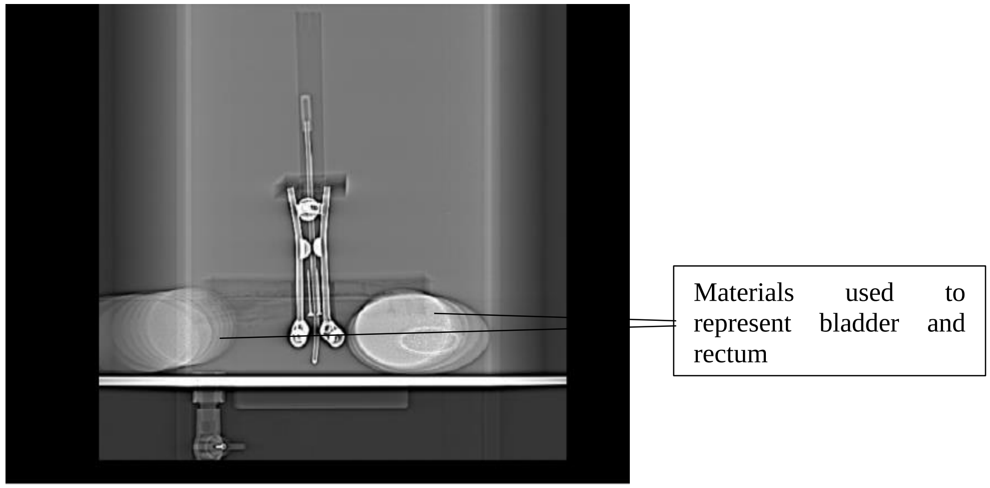

Figure 5. CT 3D image of the water phantom with applicators in the jig of the phantom.

3. Results

The radiation quantities measured were in terms of air kerma strength, ionization recombination and absorbed dose.

3.1 Comparison of 2D & 3D Imaging

CT (3D) images give better information about soft tissue as compared to x-rays (2D), which give better information about bony tissue or tissue with a high Z. MRI on the other hand, gives better soft tissue contrast but in this study CT and x-ray modalities available for consideration considered. **Figure 3** and **Figure 4** above show the differences between imaging in 2D and 3D, comparing the visualization of the fletcher applicators, blabber and rectum.

3.2 Comparison of 2D & 3D planning

The Manchester system considers point dose distribution; thus, information on volumetric dose distribution is not precisely calculated. This results in inadequate dose coverage to the tumour. The prescribed dose used in this study for the 2D LDR treatment planning was 44 Gy with point A as the point of reference. Specific doses to the materials used to represent the bladder and rectum were calculated. With 3D LDR IGBT treatment, planning made it easy to specify the dose for each volume with tangible changes in doses correlating to changes in volumes. The dose to each organ were calculated with optimized doses to the various organs using the same dose (44 Gy) used in the 2D planning. This was prescribed to a PTV which was a 2 cm volume contoured around the fletcher applicators. Table 1 represents the prescribed doses to the various organs with their dose constraints and the percentage gap of dose delivered from the OAR constraints.

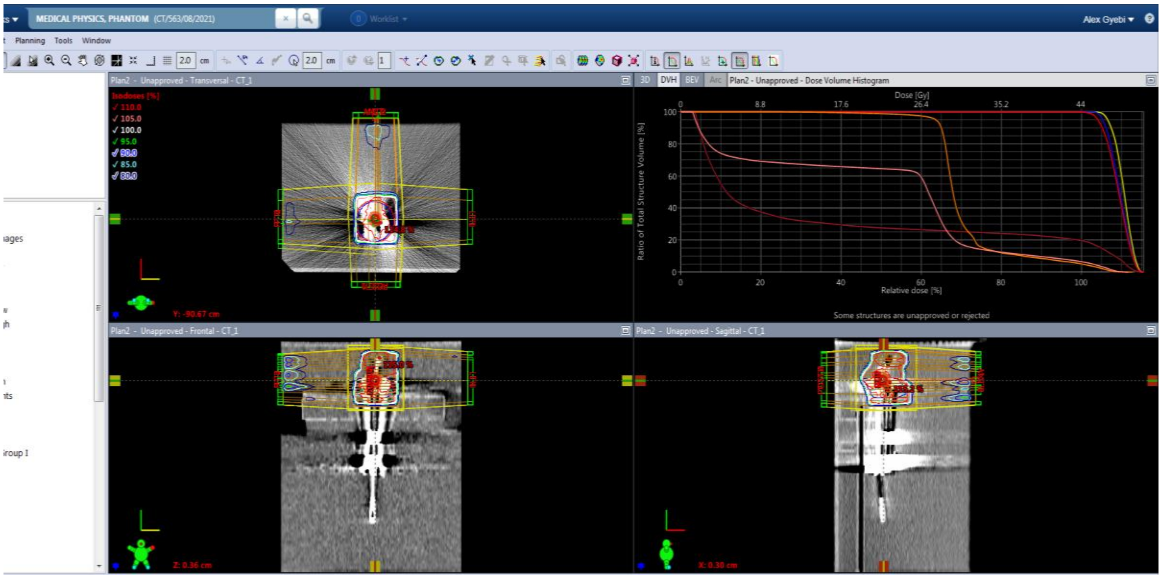

Figure 6. An image of the 3D plan done on the water phantom.

3.3 Dosimetry of air kerma strength.

The air kerma strength measurement was done using a three-point measurement system (considered 3 different distances) instead of a seven - point measurement system (considers 7 different distances) as the values were observed to decreased sharply with increasing distance. The exact exposure rates at the various distances of 2 cm, 5 cm, and 7 cm from the sources were determined using $X_l = 5.033 \times 10^{-08}$ $Ckg^{-1}s^{-1}m^{-2}$, 1.504×10^{-07} $Ckg^{-1}s^{-1}m^{-2}$, 3.191×10^{-07} $Ckg^{-1}s^{-1}m^{-2}$ respectively in order to calculate for the air kerma strengths (S_K) which were then calculated using $S_K = X_l \times l^2 \times (W/e)$, where W/e is the energy expanded per unit charge released in air.

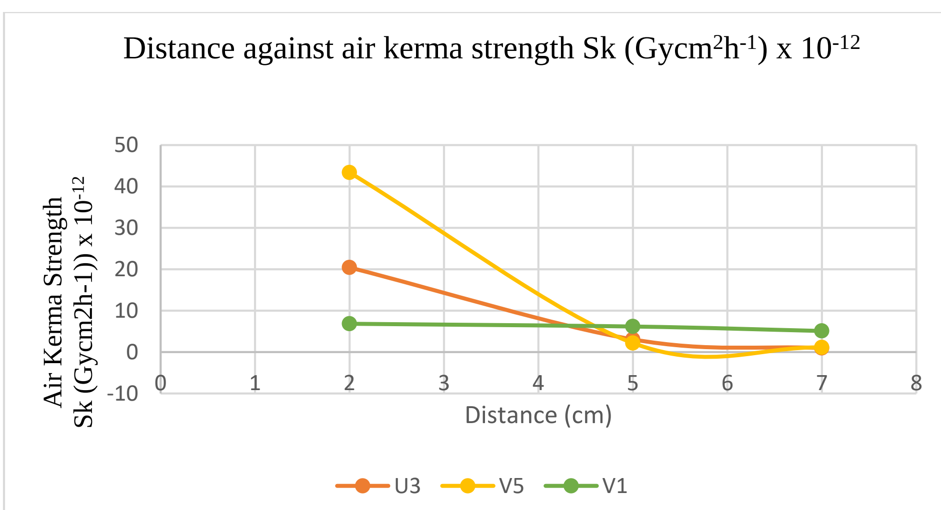

Figure 6. Graph of distance against air kerma strength Sk ($Gycm^2h^{-1}$) x 10^{-12}

3.4 Dosimetry of dose distribution

The dose measurements are taken at 2 cm, 5 cm and 7 cm from the applicators' left, top, and right directions over a 300-second period. The first observation is a dose fall off after 2 cm with increasing distances from the source which verifies the inverse square law ($1/r^2$) is observed in Figure 7. The Manchester system's dose to point A is the system mostly used in 2D planning, which may not necessarily be of harm as a high percentage of the dose is observed to be deposited at 2 cm from the source. Nevertheless, at 5 cm from the source, doses are measured, implying exposure to OARs. Furthermore, the dose distribution in 2D is point-based and hence volumetric dose distribution is not considered as done in 3D, which implies that there may be doses beyond the 2 cm margin which are not accounted for during the planning, emphasizing the limitation of 2D treatment planning in brachytherapy.

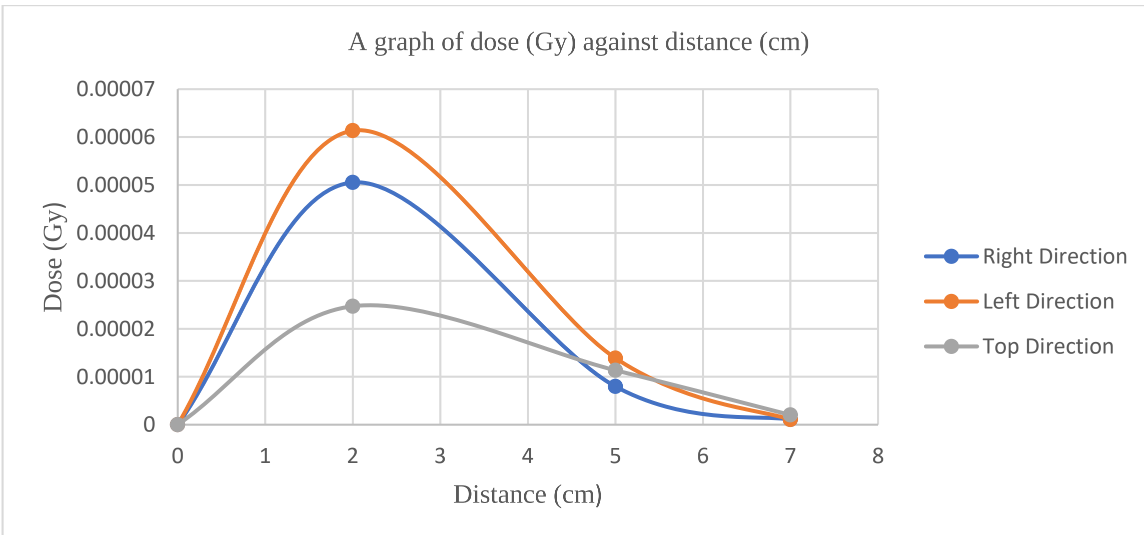

Figure 7. A graph of dose distribution for the Cs-137 sources in the applicators in the water phantom showing the relation between dose and distance.

5. Discussion

The applicators used for this study were metallic, thus giving better images with x-ray (2D) while artifacts were observed with CT (3D), making planning difficult as the images were not clear enough. This may be a limitation but due to certain technological advances CT compatible applicators are available to ensure better imaging and reduction of artifacts. Secondly, the dose distribution across the OARs is calculated for in 3D brachytherapy planning making it easy to plan and manipulate the doses to certain organs as well as the CTV and PTV. Below is a table of doses delivered to the PTV and OARs after brachytherapy planning.

Table 1. A table of showing dose delivered after 3D treatment planning

Organ Volume	Prescribed dose	Percentage delivered	Dose constraint of organ	% Gap from constraint
PTV	44 Gy	100%	No constraints	0%

Table 2. A table of showing calculated doses to OARs after 3D treatment planning

Organ Volume	Calculated dose	Percentage delivered	Dose constraint of organ	% Gap from constraint
Bladder	26.4 Gy	60%	80Gy	67%
Rectum	24.8 Gy	56.4%	75Gy	66.9%
Cervix	44 Gy	100%	No constraints (for cervix brachytherapy)	0%

6. Conclusion

Even though 2D LDR may have come with some benefits, 3D Image Guided Brachytherapy has been observed to be quite advantageous in imaging, planning, safety, and even cost. The successful construction of a water phantom was of importance in data collection and the comparison of data from both treatment modalities in brachytherapy made the variations between both modalities very clear. The water phantom could also be suitable for other experiments or studies involving external beam therapy, especially for a study of homogenous systems. It was observed that imaging in 2D highlighted more metallic or bony structures as compared to CT, which gave clearer images with tissues and more artifacts due to the utilization of metallic applicators. Regardless, planning in 3D is observed to be more optimized as doses to tumour volumes and OAR volumes are all accounted for, unlike in 2D planning where dose calculation is rather point-based. Finally, 2D LDR planning with point A as the reference point was observed not to necessarily be of importance in 3D IGBT since it follows a volumetric approach in planning.

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