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RESEARCH ARTICLE

Dose distribution in HDR brachytherapy with GafChromic film and compared with Eclipse system

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ABSTRACT

The dose distribution around the applicator in HDR brachytherapy on GammaMed+ unit using a 192Ir source was evaluated using GafChromic films. The film was calibrated using a TrueBeam linear accelerator. The experimental dose distribution results match the planned Eclipse system and also indicate that the discrepancy between the planned system and measured isodose values is approximately ±1.2%.

INTRODUCTION

High-dose brachytherapy (HDR) is a radiation therapy technique used to treat tumours or areas of the body by irradiating a sealed radiation source with a dose rate greater than 12 Gray per hour (Albuquerque et.al., 2019). Radioactive sources commonly employed include ^{60}Co, ^{103}Pd, and ^{192}Ir, with a primary emphasis on the latter (Chino, 2020). For a patient treatment it is obligatory to have a medical physicist and an attending physician and laboratory technician present, an environment in which a specialised planning system, the necessary instruments and a room corresponding to the safety requirements of the employee is required (Lim and Kim, 2021; Jam et al., 2-18). The apparatus for treatment is mainly used by Varian and Nukletron (Safigholi et.al., 2023).

In this paper a array from "Varian", model GammaMedPlus, was used, working with a planning system called External Beam Planning. Here in this planning system the patient data and the image in which the treatment plan is planned are entered. For this purpose, the following important steps are taken:

- the patient data is loaded into the system;

- the attending physician in the treatment room inserts the applicator into the patient;

- then takes an X-ray or CT scan;

- then uploads the images into the system, then the doctor draws the organs;

- then the medical physicist models the treatment plan;

- the treatment plan is then transferred to the machine that performs the therapeutic procedure.

Therapy plans undergo optimization, which can be performed either manually or automatically, based on observations of dose distribution curves in various cross-sections to ensure adequate dose distribution within the treatment zone (Khan and Gibbons, 2014). This emphasises the importance of dosimetry for each ionising radiation source used. This approach is necessary to ensure the accuracy of the dose distribution produced by a given source, which is critical to the effective and safe delivery of cancer treatment. Without accurate dosimetry, it is impossible to ensure adequate irradiation of the tumour and minimise the impact on surrounding healthy tissue.

The foundation of successful brachytherapy lies in experimental measurements, and any theoretical calculations require confirmation through practical measurements (Nagai et.al., 2020, Rashid et al., 2023). The most used method is the theoretical calculation of the dose distribution using the Monte Carlo method, which for Ir-192 and cobalt sources is used to determine the characteristic functions [g, f] (Rossi et.al., 2019).

A study of dosimetric characteristics was carried out, which used experimental methods of ^{192}Ir source measurement to determine the distribution of absorbed dose in the vicinity of the ionising radiation source. High precision dosimetric instruments were used in the study, which made it possible to analyse in detail the spatial dose distribution and evaluate its compliance with the calculated models. These data are critical for optimising dosimetric planning and improving the accuracy of brachytherapy, ensuring the most effective treatment with minimal risk to healthy tissue. For example, dose measurements using electron spin resonance (ESR) with alanine films (Anton et al., 2015) demonstrated high accuracy. Comparison of these experimental data with the results of Monte Carlo simulations revealed a deviation not exceeding 5%.

Radiochromic films have previously been used for isodose measurements because it is a very high-resolution tool for determining dose distributions (Ayoobian et.al., 2016). Monte Carlo software is used to verify isodose distributions in films (Hsu et.al., 2012; Kanval et al., 2024). Radiochromic film like Gafchromic EBT2 we can use in clinic and old model EBT (Mendez et.al., 2013).

In this research, a matrix of GafChromic radiochromic film was created to determine the dose distribution of ^{192} Ir isotope used in high-dose brachytherapy. This technique provided highly accurate data on the spatial distribution of dose around the applicator, providing detailed visualisation and quantitative analysis of the radiation distribution. After these matrices were irradiated with the same sources, then scanned with an Epson Expression 10000XL scanner. For the study analyzed by the open-source program "ImageJ" for processing the received image from the scanner. The simulated source treatment plan was performed using the planning system Eclipse, whose curves are presented here. The results of the image processing analysis were compared with the treatment plan.

2. Experimental details

2.1 Calibration of radiotherapeutic film

Gafchromic radiochromic film was used in this study. Calibration was performed by cutting the film into 2 cm squares and exposing it to TrueBeam radiotherapy equipment under standard conditions. A field size of 10 × 10 cm^2 and a source-to-surface distance (SSD) of 100 cm were used, with solid water as the medium. Subsequently, each film was scanned at a resolution of 600 dots per inch using an Epson Expression 10000XL scanner. The resulting image of each film was divided into RGB components, and all subsequent work was carried out exclusively with the red component. To create reference points on the film, it was exposed to various doses, specifically 2 Gy, 4 Gy, 7 Gy, 14 Gy, and 28 Gy, using a 6 MeV energy source.

2.2 Set up system

The experimental setup for measuring the dose distribution was as follows: first, a radiochromic film measuring 10 cm × 10 cm was prepared. Then, two frames with a thickness of 5 cm each were prepared and positioned perpendicular to the plane of the film, forming a 10 cm × 10 cm area. A dosimetry film was placed between these frames. In the center of the film, a slit was created through which an applicator was inserted. The layout of the dosimetry film and a photograph are shown in Figure 1. In the experiment, a radioactive source, ^{192}Ir, with an activity of 6.371 Ci (at the time of the experiment) was used.

Fig. 1: Experimental array

2.3 Film irradiating

The External Beam Planning v8 brachytherapy system with an 8 centimetre long active part was used for dose distribution modelling and planning. This system automatically optimized the dose to achieve values of 4 Gy and 7 Gy at a distance of 2 cm.

For experimental research, a grid was developed that accounted for the perpendicularity of the source trajectory to the film plane. Along the length of the applicator, three films were placed, with two of them situated within the radiation field of the source (Figure 1). During the study, two different types of films were irradiated: Gafchromic HD-V2 type and Gafchromic RTQA2 type.

3. RESULTS AND DISCUSSION

A visualization of the dose distribution resulting from the simulation is presented in Figure 2. This dose distribution of ^{192}Ir was simulated using the Eclipse system. Figure 2b displays the dose distribution along the length of the applicator, along with the placement of films. These films were intentionally positioned for subsequent comparison of the simulation results with experimental dose measurements along the profile. Figure 2a shows isodose profiles for the location of a Gafchromic RTQA2 film. The red dot represents a distance of 2 cm from the source, and 4 Gy corresponds to the planned dose.

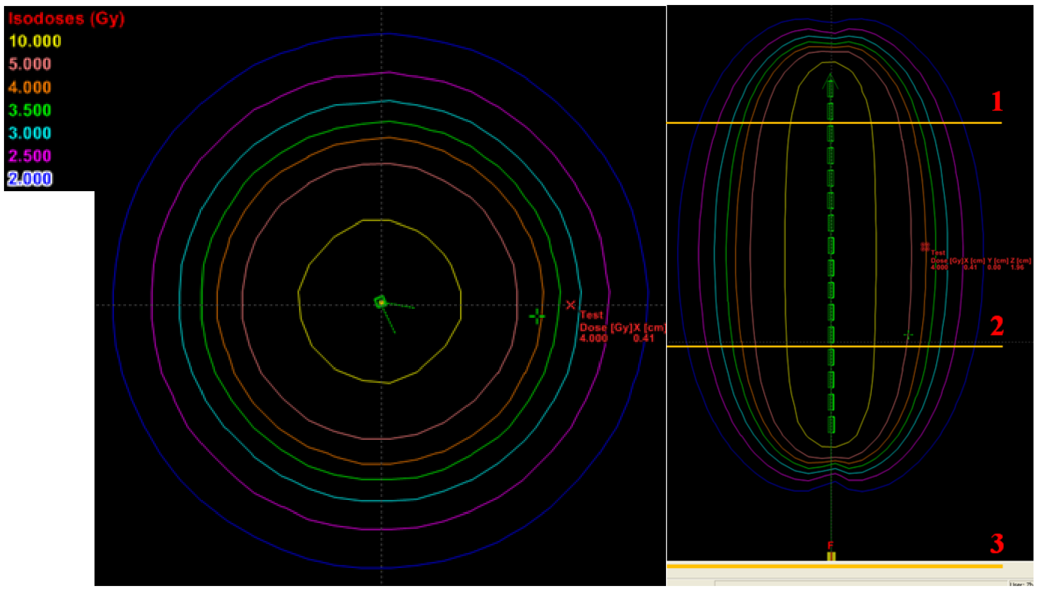

Fig. 2: Iso-dose curves from Ir-192 planned using the Eclipse system.

3.1. Study of the film

Initially, GafChromic films were scanned using an Epson Expression 10000XL scanner. Then the obtained images were subjected to detailed analysis using specialised software ImageJ version 1.52.. Films with the same energy response exhibited homogeneous performance when exposed to various radiation sources. For each film sample, analyses were performed that included examining random radial dose profiles and then comparing them to those of other films. The orientation of these profiles can be seen in Figure 3, which was programmatically cropped to a square shape measuring 5×5 cm. The characteristics of dose distribution profiles remained stable in the investigated area located at a distance of 2 cm from the source. These parameters are comparable to the characteristics of the Eclipse dosimetry system, confirming high accuracy and reproducibility of measurements.

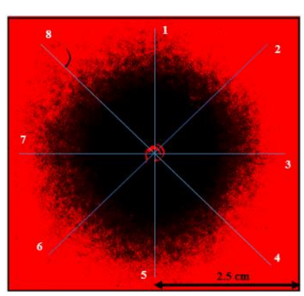

Fig. 3: Orientation of dose analysis profiles obtained using the ImageJ v1.52 software

On the modeled plan (Fig. 2), there are more isodose curves observed than on the radiochromic film (Fig. 4). In Fig. 4, the required isodoses we need are highlighted on the film. The difference between Gafchromic RTQA 2 and HD V2 films is clearly visible, due to, firstly, the design of the applicator and the source, and secondly, the source moving along the inner part of the applicator.

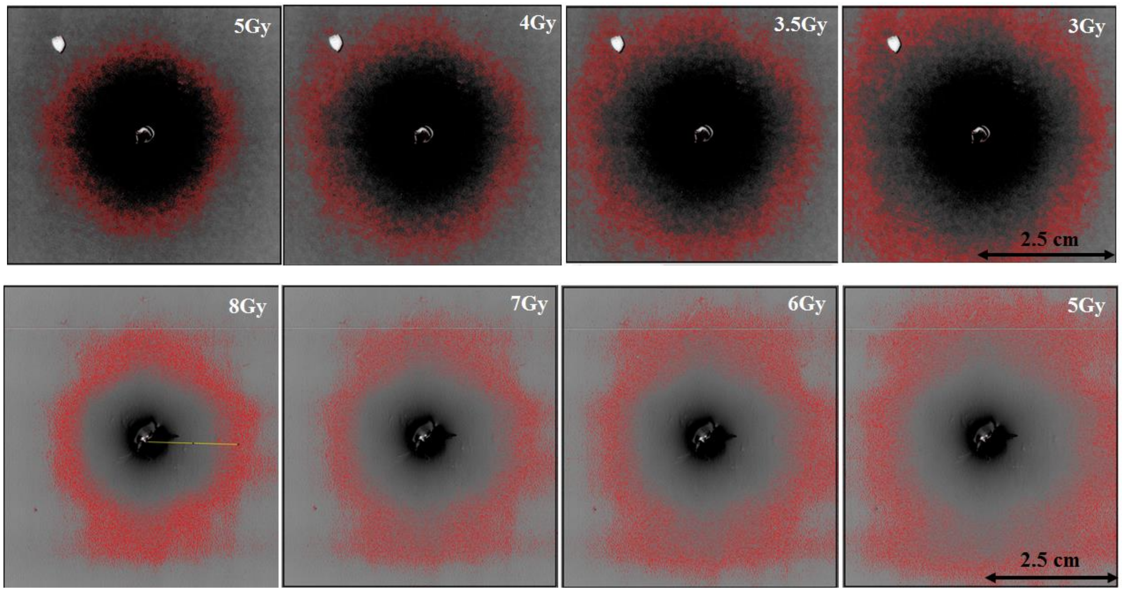

Fig. 4: Dosimetric distribution cartography, with Gafchromic RTQA 2 film on top and HD V2 film on the bottom

In figure 5, a graph is presented to compare isodose curves, demonstrating repeatability and reproducibility (s 10%). The measured profiles exhibit similar conduct; however, there is high non-uniformity observed in the vicinity of the source due to a steep dose gradient. Conversely, at smaller distances, less non-uniformity is observed (Table 1).

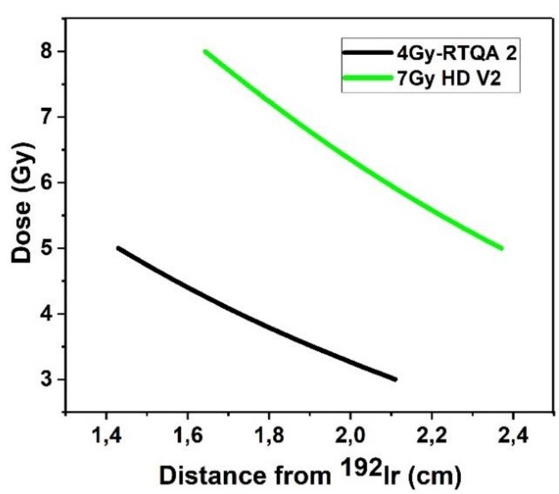

Fig. 5: Isodose profile of different films at various doses.

Table 1: Comparison of doses at different distances through the film (RTQA 2).

Film	Distance in the direction from the center, cm							
Dose	1	2	3	4	5	6	7	8
3 Gy	2.11	2.08	2.03	2.09	2.12	2.17	2.13	2.12
3.5 Gy	1.89	1.87	1.92	1.93	1.95	1.96	1.91	1.88
4 Gy	1.71	1.73	1.74	1.75	1.76	1.75	1.73	1.71
5 Gy	1.43	1.42	1.44	1.45	1.46	1.44	1.45	1.42

Using the Eclipse system, a 4 Gy dose was planned to be delivered at a distance of 2 cm from the line source, assuming its homogeneous distribution at this point as at the line source. The measured dose for each film in different directions at a distance of 2 cm is shown in Table 2. At the specified distance, the average measured dose detected by the films was 4 Gy with a measurement accuracy within 1.2%.

Table 2: Comparison of dose per direction on films at a distance of 2 cm.

Films	Direction, Dose, Gy								average	deviation
RTQA 2	1	2	3	4	5	6	7	8		
	3.74	3.72	3.75	3.77	3.78	3.80	3.77	3.73	3.7575	1,2%
HD V2	1	2	3	4	5	6	7	8		
	6.22	6.23	6.25	6.24	6.21	6.19	6.21	6.20	6.2188	0.5%

4. CONCLUSION

The dose distribution from the isotope ^{192}Ir used in high dose rate brachytherapy (HDR) was measured using Gafchromic radiosensitive films. The obtained data were then compared with the planned dose distribution obtained using the Eclipse system. The difference between the planned and measured dose distributions using RTQA 2 and HD V2 films was found to be ±1.2%, indicating high accuracy and consistency of the measurements. The results indicate that this is a straightforward and practical method that can be incorporated into quality control procedures, taking into account variations caused by the energy of the radiation source.

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