DEVELOPMENT OF A TRANSPARENT AND DEFORMABLE TWO DIMENSIONAL RADIOCHROMIC GEL DOSIMETER

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Summary

Achieving accurate small field dosimetry is challenging; however, an accurate dose verification tool to evaluate the delivered dose distribution of radiotherapy is essential. In this research, a 2D radiochromic gel dosimeter is developed and characterized. A radiosensitive dye, leucomalachite green (LMG) is dissolved in gelatin. The changes in absorbencies of the gels were measured as a function of absorbed dose and a linear dose response is achieved above 10Gy. The gels were then irradiated using complicated Intensity-modulated radiation therapy (IMRT) beams and their dose distributions were compared to their respective simulated/calculated planar dose maps.

1. Introduction

The aim of radiotherapy is to deliver a uniform high dose of radiation to a tumour while sparing the surrounding healthy tissues. To reduce the risk of damaging the surrounding healthy tissue, it is of utmost importance to verify the 3D dose distribution prior to the start of treatment. Many dosimetry techniques are being investigated to verify these dose distributions. In turn, gel dosimeters have appeared as one of the candidates for this purpose [1]. One of the most important applications of gel dosimeters in radiation therapy quality assurance is the verification of dose distribution.

Gel dosimeters are radiosensitive materials that, upon irradiation, undergo changes in their chemical structure as a function of absorbed radiation dose. The absorbed radiation dose distribution may be recorded in three-dimensions depending on the type of gel dosimeter used. Furthermore, gel dosimeters may be modified to be soft-tissue equivalent, and depending on the application, their physical properties may be modified.

The objective of this research is to fabricate a transparent and deformable radiochromic gel dosimeter that may be used as quality assurance tool; moreover, fabricating an inexpensive gel dosimeter in a clinical environment that may be analyzed using a simple optical read-out technique is of great interest. Radiochromic gels are dosimeters that change colour upon irradiation. A radiosensitive dye, leucomalachite green (LMG) is dissolved in a gelatin matrix to record the dose distribution in 3D. LMG changes colour upon irradiation, and has an absorbance band of 629nm.

2. Radiochromic Gel Dosimetry Methodology

To develop the radiochromic gel dosimeter, the effect of radiation on the leuco dye and free radical initiator are examined and gels were formed in cuvettes to facilitate 1D optical measurement. Then, the 5mm thick two-dimensional films are fabricated to be used as quality assurance tools, and verify the computer simulated 2D dose map.
Figure 1. shows the four steps required to investigate the in-house radiochromic gel.

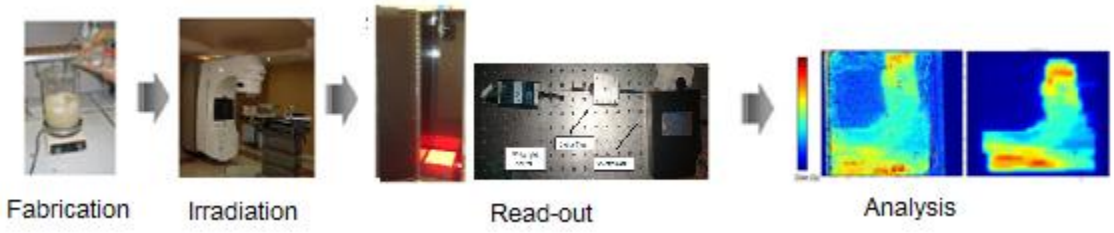

Figure 1 Steps involved in investigating the in-house radiochromic gel

2.1 Fabrication

As shown in Table 2.1 the gelatin-based dosimeters were fabricated using five main components: the matrix complex (gelatin and water), radiosensitive dye (LMG), free radical initiator (CCl4 or CHCl3) (Sigma-Aldrich, St. Louis, USA), trichloracetic acid (Cl3COOH) (Sigma-Aldrich, St. Louis, USA), and surfactant Sodium dodecyl sulphate (SDS) (Sigma-Aldrich, St. Louis, USA)
Different concentrations of CHCL3, CCl3COOH and LMG were studied; however the highest radiosensitivity was achieved using the values given in table 1. [2,3,4].

Table 1 Summary of chemical concentrations.

	Molar Concentration (mM)	%(w/W)
LMG	0.38	0.01
CHCl3	80	1.21
CCl3COOH	5	0.06
SDS	50	1.34
Gelatin		5.55
Water		91.83

The free radical initiator improve the effect of radiation sensitivity by forming highly reactive species such as OH•, H_2O_2• and Cl•, which oxidize LMG to its chromatic form. The surfactant, SDS, leads to the appearance of a stronger absorption band [5].

2.2 Irradiation

Radiation was produced using a Varian 2100iX linac delivering 6MV photons at 400 monitor units per minute. Radiation was delivered to the cuvettes using a 20 x 20 cm^2 open field. The cuvettes were placed in a water bath to try to achieve electronic equilibrium throughout. The 2D

films were characterized using 10x10 open fields. For comparison of the dose distribution in the fabricated gels with the simulated dose map, calculated by a treatment planning system (Pinnacle 8.0m), six different IMRT treatment beams were used to deliver radiation.

2.3 Optical Measurements

The irradiated leuco dye turns green with an absorption peak at 629nm. The attenuation profiles of unirradiated and irradiated samples were analyzed at that specific wavelength. The change in optical density of samples post irradiation directly correlates with the absorbed dose (Figure 2). Hence, using Beer-Lambert law:

is the extinction coefficient in , is the concentration of absorbing molecule in [M] and L is the optical path length in [cm].

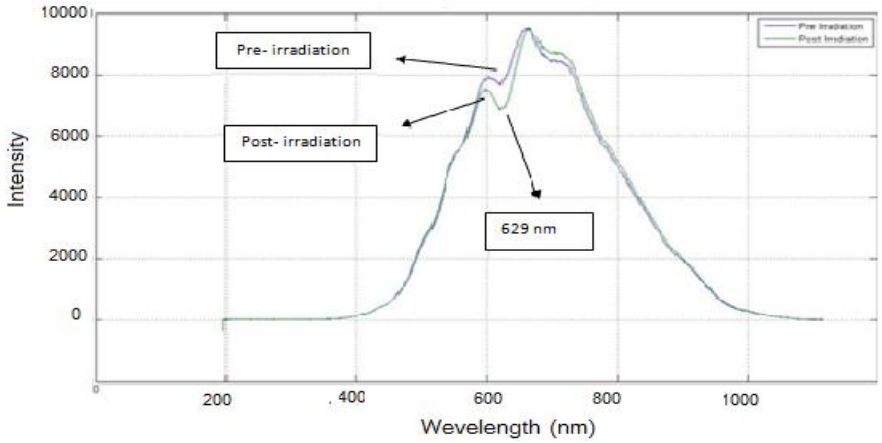

Figure 2 At 629 nm the intensity of transmitted light, pre-post irradiation, differs due to absorption by LMG

The change in optical density was obtained using a simple linear transmission apparatus for 1D gels; and CCD camera apparatus for 2D gels, as shown in figure 3.

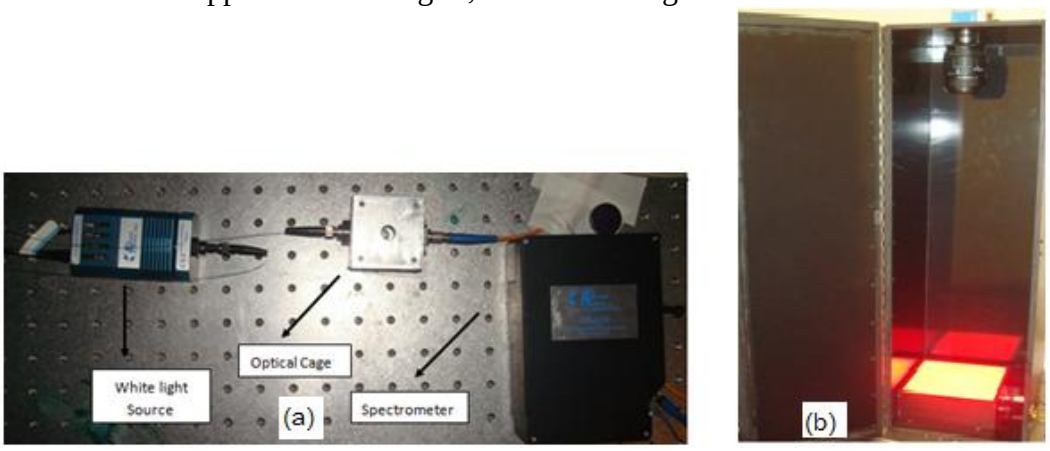

Figure 3. in-house (a) linear transmission apparatus (b) CCD camera apparatus

2.4 Data Processing and Analysis

The images captured by the CCD camera were transferred to a computer. The images were 1024 X 1328, with pixel values that corresponded to the intensity of the transmitted light.

Accordingly, the absorbance was calculated at each pixel. However, the images must be smoothed and transformed before calculating the absorbance. The measured image must be compared with the computer simulated dose-map images and must be mapped onto each other. Hence, the images were de-noised, rotated, stretched and transformed before calculating the absorbance.

3. Characterization of Developed gel Dosimeter

The change in optical density as a function of absorbed was obtained for both 1D gels and 2D gels. They both show linear relationships above certain threshold.

Figure 4(a) shows the dose response of 1D gel for 36 experiments and figure 4 (b) shows the dose response for 2 gel for 8 trials.

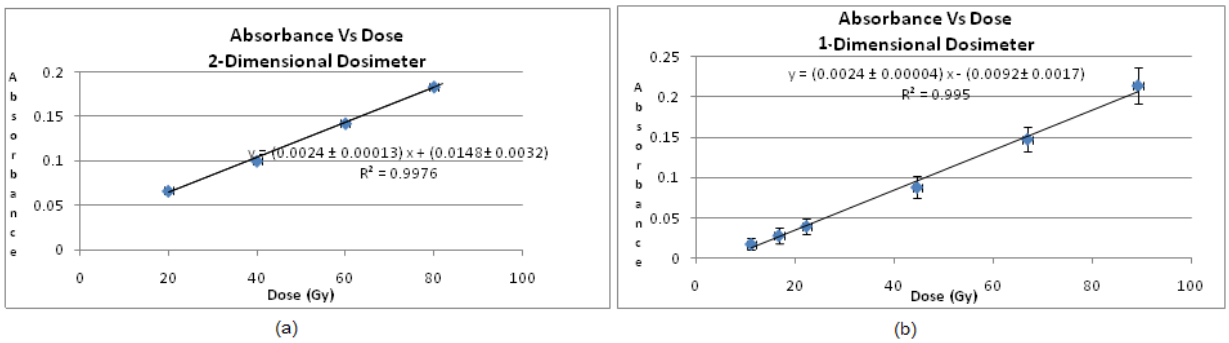

Figure 4.The error bars on the absorbance represent the standard deviation in different trails, the error bar on the absorbed dose is the error associated with conversion of monitor units to cGy, which is less than 5%.

The absorbance as a function of absorbed dose for both 1D and 2D gels can be modeled as follow:

$$= (0.0024 \pm 0.00004)\, x - (0.0092 \pm 0.0017)$$
$$= (0.0024 \pm 0.00008)\, x + (0.0148 \pm 0.0022)$$

The sensitivity of the in-house radiochromic gel dosimeters was consistent over a wide range of radiation doses, as there was less than 1% uncertainty in the slope of the absorbance *versus* dose curve. The uncertainty was greater for the y-intercept of the curves This suggests there was a large systematic error in the initial condition of the dosimeters. This uncertainty, which is the deviation of absorbance at no dose, may be due to different factors such as sensitivity of LMG to light and heat.

4. Verification of 2D Dose Distribution

Six different IMRT fields were delivered to the 2D gels as a proof of principal test. The measured profiles were then compared to computer simulated (PCP) dose maps. Figure 6 shows a sample calculated dose map of one of the IMRT fields.

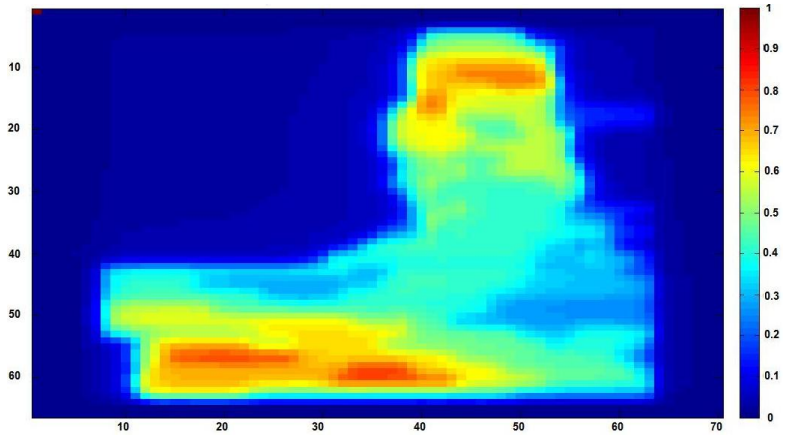

Figure 5 Computer simulated (PCP) planar dose map of IMRT field.

As shown in figure 5 the dose should be distributed non-uniformly on the gel. After irradiating the gels and calculating the absorbance at each pixel, the measured dose distribution image must be mapped onto the computer simulated (PCP) image. Hence, the measured image must undergo different stages of data processing..

In Figure 6, the different stages of data processing are shown. Image shown in panel (a) is the raw image, which is obtained right after the gels are being irradiated. Image (b) is the denoised image which was then (c) mapped onto computer simulated image (d). After, a point by point comparison performed.

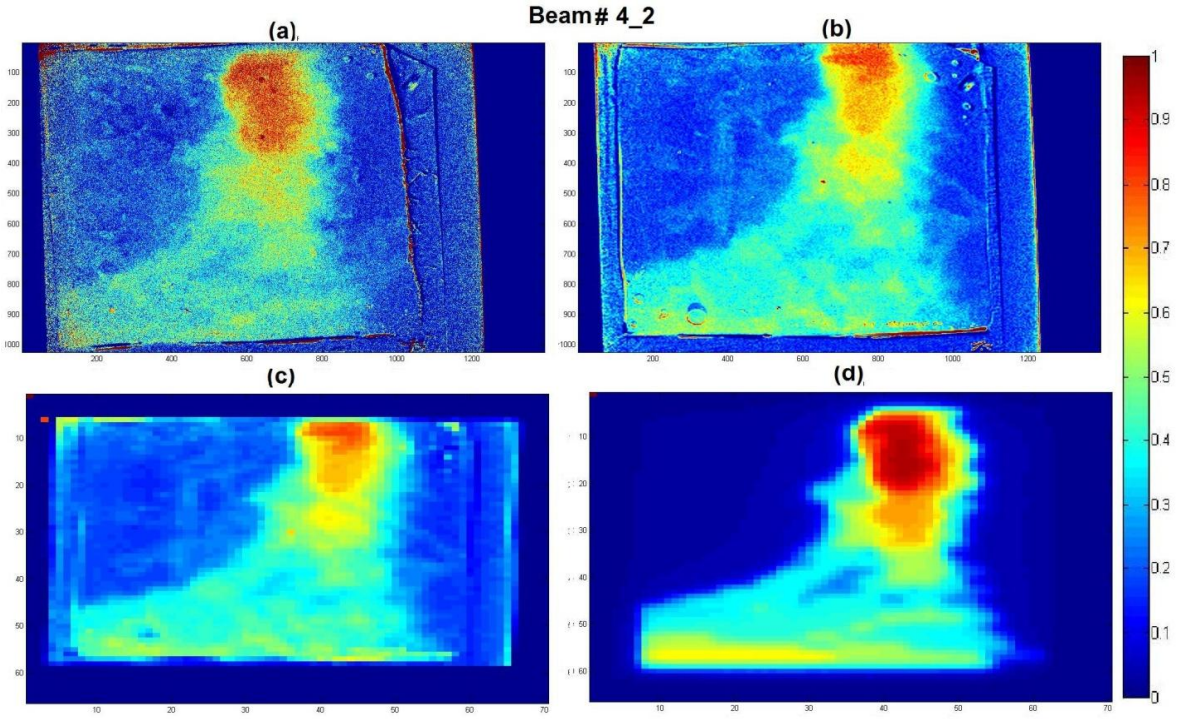

Figure 6 (a) Raw absorbance map, the absorbance was computed at each pixel. **(b)** The images were De-noised through wavelet transform and noise reduction, **(c)** The measured images were mapped onto the PCP image and down-sampled; **(d)** Computer Simulated (PCP) image. The color is the relative absorbed dose (Max =80Gy)

Comparing the dose distribution in our developed 2D gels with the computer simulated planar dose map there is an uncertainty of approximately 0.35, which is relatively high. The source of this uncertainty is likely from the data processing and down-sampling the image. In order to reduce this error, a better a data processing method should be developed.

As shown in figure 6, the measured image computed from the absorbance of the gel was similar to the computer simulated PCP designed beams. Even though the dose distributions matched well, the sensitivity of the gels must be improved to be used as a quality assurance tool

5. Conclusion

The proposed radiochromic gel dosimeter has a linear dose response above 10 Gy. Their production, in principle, is relatively easy and inexpensive. Furthermore, they do not have the oxidation problem associated with other dosimeters. Therefore, gelatin based radiochromic dosimeters doped with LMG has a promising future.

There was a relatively large error associated with the gels in these experiments, but the error could be minimized by utilizing more accurate laboratory equipment for fabrication, and also utilizing a more accurate data processing technique.

In conclusion, the in-house 2D radiochromic gel dosimeters hold promise for use as quality assurance tools in the cancer clinics. Even though the dosimeters have a linear dose response over a wide range of dose levels, increasing the sensitivity of the dosimeters should be the focus of future research in this field. Furthermore, the dose distributions recorded by the gels are qualitatively and quantitatively similar to the computer simulated (Pinnacle Calculated) Planar designed dose maps. Although it was observed that the fabricated gel dosimeters could be used for quality assurance purposes, they must go through many more stages of research to be used clinically.

6. References

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