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Three-dimensional dosimetry imaging of I-125 plaque for eye cancer treatment

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Abstract
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Keywords
Three, dimensional, dosimetry, imaging, 125, plaque, for, eye, cancer, treatment

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Abstract

Treatment of ocular cancers using eye plaque brachytherapy is now an established medical procedure. However, current QA for these eye plaques is quite rudimentary, limiting the opportunities for precise per-tumour plaque customisation. This paper proposes and experimentally validates a new technique for imaging of eye plaque dose distributions using a high-resolution pixelated silicon detector. Results are presented demonstrating the 2D and 3D isodose surfaces produced using experimental data collected using this method.

Keywords: brachytherapy; ocular cancer; dosimetric imaging; pixelated detector

1. Introduction

Melanoma and squamous cell carcinoma are the most prevalent ocular malignancies in adults [1]. Disease morbidity and cost to the community is significant with almost 50% of patients losing vision or the eye due to the disease and/or the treatment [2,3]. Ocular melanoma is typically treated by resection of the surgical mass or for progressed tumours, via enucleation [4]. However, radiotherapy remains the most widely used treatment for posterior uveal melanoma, which carries a serious prognosis, especially if the tumour is medium or large in size [4]. Brachytherapy using radioactive eye plaques is the preferred method of treatment for patients with ocular malignancies.

Eye brachytherapy involves the surgical insertion of a radioactive plaque behind the tumour residing within the eye of the patient. At present, the most popular eye plaques used for treating ocular cancers incorporate I-125 seeds or are uniformly coated with a radioactive material such as Ru106/ Rh106 [5].

There are currently no procedures with the ability to provide quality assurance (QA) for customised plaques, taking into account factors such as tumour shape, location, and proximity to vital structures,

such as the optic nerve and macula which have been shown to receive up to 85% and 58% respectively of the prescribed dose during treatment[6]. This can result in optic neuropathy and macular degeneracy [7]. Furthermore, when the primary treatment fails to completely eradicate the tumour, the prognosis in terms of eye and sight preservation as well as survival becomes significantly reduced [4]. Overall, the failure rate after eye plaque brachytherapy is reported to be up to 10% and is a result of inaccuracies in dosage as well as the surgical placement of plaques [1].

Experimental dosimetry in ocular radiotherapy, where tumours are small and can be close to critical structures such as the optical nerve, demands high spatial resolution dosimetry and high detector dynamic range due to the steep dose gradients involved. A new approach is required to provide real time, high spatial resolution, low dose rate dosimetry for eye plaque QA.

QA of Ru-106 plaques using single fibre optic plastic scintillator dosimeters has previously been reported [8, 9]. However, this requires a slow and complex scanning assembly to obtain 2D dose distributions and is limited in spatial resolution due by the size of the device (1.0x0.5mm) [8, 9]. Spectroscopic dosimetry, based on silicon radiation detectors, has been successfully used for point dosimetry in low dose rate brachytherapy utilising I-125 seeds [10]. A pixelated, 2D array of such detectors, used in spectroscopy mode, is well suited for QA of eye plaque dosimetry. Silicon pixelated detectors such as the Medipix2 [11] and Timepix have been successfully used in radiography, neutronography, and micro-tomography [12] and are currently being investigated for eye plaque dosimetry at CMRP. These devices consist of an array of individual detectors (55x55μm pixels) [12]. Silicon pixelated detectors operating in spectroscopy mode can generate dosimetric images when placed below the treatment plaque within a phantom. The dosimetric images can be used to generate three-dimensional dose functions with a high spatial resolution providing the desired dosimetric QA of the treatment prior to the procedure.

2. Method

The silicon pixelated detector, Medipix2, was used to obtain two dimensional dose distributions in several planes within a segmented 24mm diameter Perspex eye phantom. A 15mm ROPES stainless steel eye plaque, loaded with Oncura 6711 I-125 based seeds, was attached to the phantom. Medipix2 calibration was performed on the central axis of the phantom with a single I-125 seed and the TG-43 protocol. Absolute calibration was conducted with one seed at depth 5mm. These results were compared with values predicted by the TG-43 treatment planning software (TPS) developed at CMRP to verify the dosimetry setup.

Two seed configurations of the eye plaque were tested; an asymmetric 5 seed distribution, and a full 10 seed distribution. Measurements at various planar angles were performed for the two seed configurations. With the plaque mounted on the top of the phantom, 2D dosimetric images were obtained using the Medipix2 at depths of 5, 10, 15, 20 and 25mm from the surface of the eye phantom closest to the plaque and calibrated using the previous depth-dose measurements. The 25 mm measurement was repeated with the plaque mounted at angles of 18º, 45º, 75º, and 90º normal to Medipix2 plane. The resulting orthogonal and oblique 2D dosimetric images, with spatial resolution of 55um were used for reconstruction of 2D isodose lines and 3D isodose surfaces.

3. Results

The relative depth response of the Medipix2 was in agreement with the TG-43 depth dose distribution of a single seed to within 2%. Good conformity was achieved with the depth dose predicted by the TPS for this seed configuration of eye plaque.

The depth planes measured by the detector can be seen in the left image of Figure 1 as a stack of 2D dosimetric images. The right hand image shows the calibrated isodose surfaces generated from the 2D dosimetric images. The 3D reconstruction of the series of planar angle dosimetric images can be seen in Figure 2.

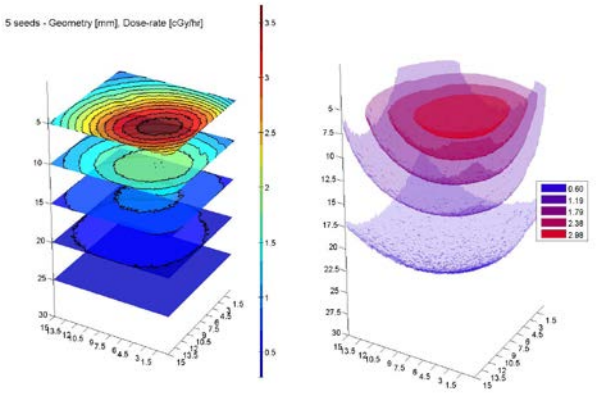

Figure 1: Two dimensional measurements used to create isodose surfaces of plaque loaded with five I-125 seeds

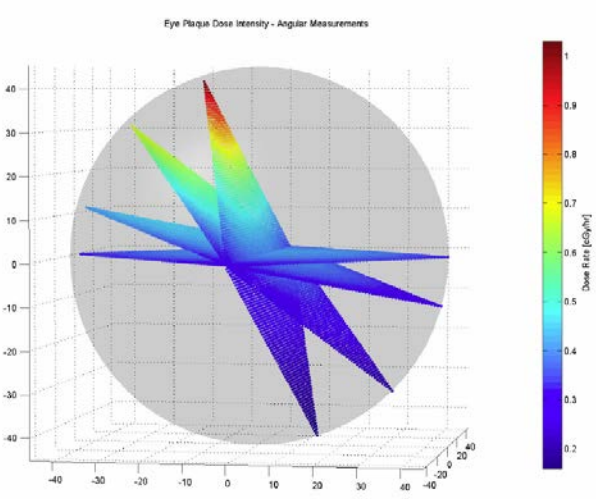

Figure 2: Reconstructed image using a number of two dimensional planar angles for 5 seeds plaque.

4. Discussion

The unique approach and system utilising pixelated detectors for fast, real time 3D dosimetric imaging for eye plaque QA will support the development of new medical procedures for the realisation of patient-specific plaques with the best customised dose distribution for each unique tumour. With a data acquisition time of just seconds and a high spatial resolution, this system overcomes many of the current limitations in dosimetry for clinical treatment, providing 3D dose imaging through the entire eye. This research provides significant evidence to suggest the feasibility of the customisation of eye plaques to optimise brachytherapy treatment of patients with eye melanomas as well as offering an accurate and real time QA system for treatment planning verification.

An improved plaque-sensor distance control method is currently being evaluated at CMRP. The process involves the use of a linear actuator to control the plaque-detector distance within a liquid environment.

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