

## Semi-3D dosimetry of high dose rate brachytherapy using a novel Gafchromic EBT3 film-array water phantom

AL Palmer<sup>1,2</sup> A Nisbet<sup>1,3</sup> and DA Bradley<sup>1</sup>

<sup>1</sup>Department of Physics, Faculty of Engineering and Physical Science, University of Surrey, UK

<sup>2</sup>Medical Physics Department, Queen Alexandra Hospital, Portsmouth Hospitals NHS Trust, Portsmouth, UK

<sup>3</sup>Medical Physics Department, Royal Surrey County Hospital NHS Foundation Trust, Guildford, UK

E-mail: antony.palmer@porthosp.nhs.uk

**Abstract.** There is a need to modernise clinical brachytherapy dosimetry measurement beyond traditional point dose verification to enable appropriate quality control within 3D treatment environments. This is to keep pace with the 3D clinical and planning approaches which often include significant patient-specific optimisation away from 'standard loading patterns'. A multi-dimension measurement system is required to provide assurance of the complex 3D dose distributions, to verify equipment performance, and to enable quality audits. However, true 3D dose measurements around brachytherapy applicators are often impractical due to their complex shapes and the requirement for close measurement distances. A solution utilising an array of radiochromic film (Gafchromic EBT3) positioned within a water filled phantom is presented. A calibration function for the film has been determined over 0 to 90Gy dose range using three colour channel analysis (FilmQAPro software). Film measurements of the radial dose from a single HDR source agree with TPS and Monte Carlo calculations within 5 % up to 50 mm from the source. Film array measurements of the dose distribution around a cervix applicator agree with TPS calculations generally within 4 mm distance to agreement. The feasibility of film array measurements for semi-3D dosimetry in clinical HDR applications is demonstrated.

### 1. Introduction

Brachytherapy treatments are currently undergoing a period of significant innovation and rapid modernisation, including a fundamental shift away from the use of traditional pre-determined dose distributions and a change from 2D to 3D perspectives of the entire treatment process. It is essential that quality assurance techniques keep pace with developments in brachytherapy treatment planning and delivery to ensure an appropriate level of dosimetric accuracy and quality. Traditional methods of quality control are based solely on isolated source-strength measurements with very little independent measurement of the actual dose delivery: This is inadequate for modern 3D-based brachytherapy which requires multi-dimension verification measurements of the dose delivered when using clinical treatment applicators and the potential of significant patient-specific dose distribution optimisation.

There is however a lack of established methods for quality control measurements of 3D dose distribution delivered by HDR treatment equipment [1]. The measurement challenge in brachytherapy is particularly difficult due to extremely steep dose gradients (6% per mm at the target volume in HDR



gynaecology treatments) and orders of magnitude variation in dose deposition across the region of interest. Measurement systems must also be sufficiently flexible to accept a range of HDR applicator designs and provide data within the maximum extent of the applicator dimensions.

Radiochromic film has been used in brachytherapy dosimetry by many investigators over the last decade to make specific measurements or to verify Monte Carlo generated TG43-based source model data [2-4]. However there have been no publications to date utilising the latest Gafchromic EBT3 radiochromic film in brachytherapy applications. There have also been only limited publications on quality control audit methods for brachytherapy dosimetry, all being based on point dose measurements, normally with ion chambers or alanine [5-7]. Further development of practical measurement and analysis techniques is required both for routine in-clinic quality checks of brachytherapy equipment performance and for independent 3D brachytherapy dosimetry audits.

We present a novel film-array test object using EBT3 film and multi-channel dosimetric analysis, suitable for use in quality control or quality audit measurements in HDR brachytherapy. We also evaluate the EBT3 manufacture's useable dose range statement "1 cGy to > 40 Gy", which is particularly relevant for brachytherapy applications [8].

## 2. Methods and materials

All measurements were performed using Gafchromic EBT3 (ISP Advanced Materials, New Jersey, USA) from a single batch. HDR exposures were performed with the Eckert & Ziegler BEBIG GmbH MultiSource® HDR treatment unit with a Co-60 source. Films were scanned using a 48-bit rgb transmission film scanner (Epson Perfection V750 Pro) at 96 dpi with no colour or sharpness corrections and consistent orientation and time-since-exposure protocol. Images were analysed in three colour channels using FilmQAPro® software (ISP Advanced Materials, New Jersey, USA). Treatment planning system (TPS) dose calculations were made with the Eckert & Ziegler BEBIG GmbH HDR Plus® software, utilizing a TG-43 based dose calculation.

### 2.1. EBT3 calibration

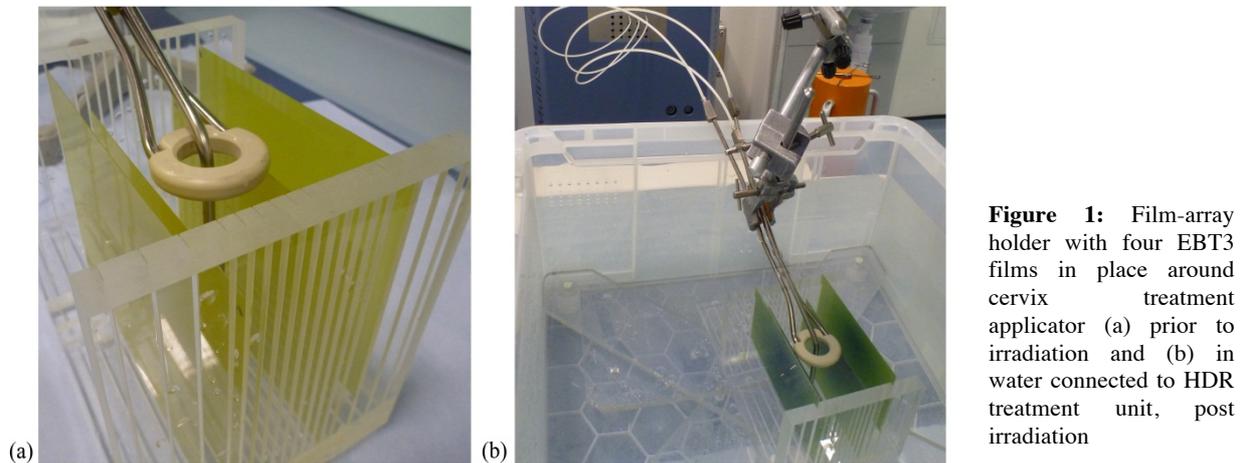
The dose response of the EBT3 film was evaluated by exposing 5 cm width strips positioned on the central axis in a 10 x 10 cm treatment field from a 6 MV linear accelerator (linac) treatment unit, to doses from 0 to 90.7 Gy. The output of the linac having been measured immediately preceding the EBT3 exposures, with three ionization chambers with calibrations traceable to a primary standard held at the National Physical Laboratory, Teddington, UK.

### 2.2. Film-array measurements

The film-array water phantom is shown in figure 1. A three-sided Perspex holder was accurately machined to precisely locate parallel EBT3 films in water, eleven central films at 5.0 mm separation, and three outer films at 10.0 mm separation. The holder was positioned centrally within a 50 litre water tank to provide near full scatter conditions. A clamp and stand was used to position the HDR applicator within the film array using alignment guides. Symmetric films at the same distance from the applicator (left and right) were used as consistency checks of the applicator and film alignment.

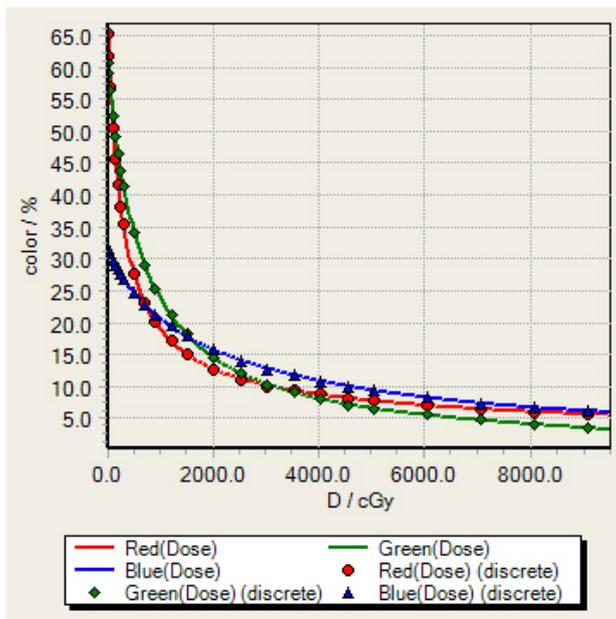
*2.2.1. Single dwell point measurement.* The dosimetry system was validated by measuring the dose with radial distance from a single source, repeating the measurement with three separate films, and comparing results to previously published Monte Carlo generated TG43 dose model parameters [9] and treatment planning system predicted dose points.

*2.2.2. Clinical treatment applicator measurement.* The dose distribution in several 2D planes around a clinical cervix applicator (Eckert & Ziegler BEBIG ring and intrauterine (IU) tube) was measured using the EBT3 film-array phantom: This enabled a semi-3D verification of the intended dose distribution. These images were compared to the isodose distribution calculated by the treatment planning system.

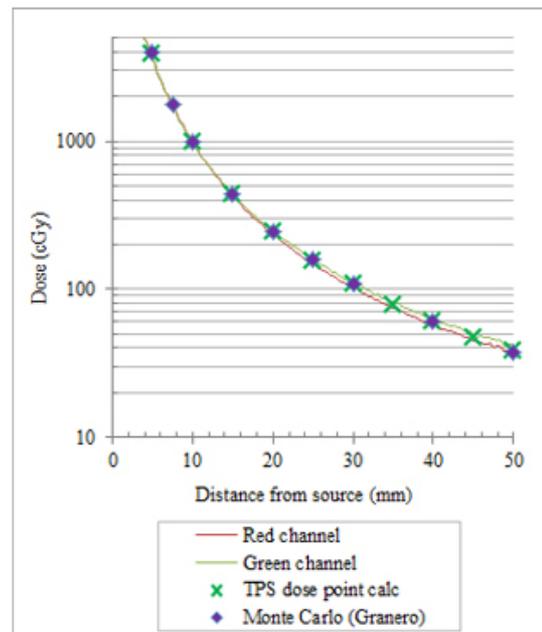


### 3. Results

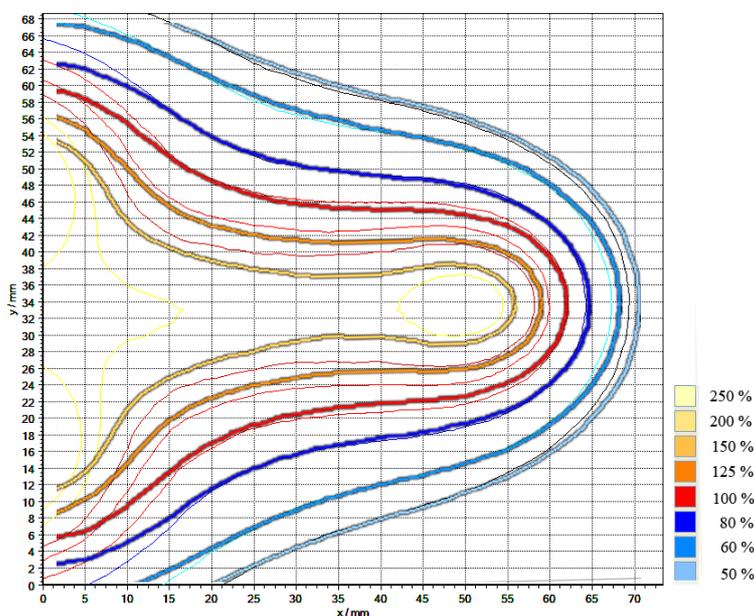
Figure 2 shows the EBT3 colour channel response as a function of dose and the applied cubic calibration fit to the red, green and blue channels over a 0 to 90 Gy range. Figure 3 shows the calibrated film dose response for the red and green channels as a function of radial distance in the case of a single isolated source, compared to TPS and Monte Carlo calculation. Figure 4 shows an isodose comparison of the EBT3 measured and TPS calculated dose distributions in a plane 1 cm above the IU channel of the clinical applicator. In general distance to agreement between the sets of isodose lines is within 4 mm.



**Figure 2:** Calibration fit of red, green & blue film channels, over 0 to 90 Gy, using FilmQAPro®



**Figure 3:** EBT3 measured dose compared to TPS and Monte Carlo from single source



**Figure 4:** Comparison of EBT3 measured (thin lines) and TPS calculated (thick lines) isodose distribution, 50 to 250 %, for 8.5 Gy prescription dose.

#### 4. Conclusions and Discussion

The use of Gafchromic EBT3 film for brachytherapy applications has been successfully demonstrated, with a calibration curve up to 90 Gy established. The film measurement technique has been successfully validated for the case of a single dwell against TPS and Monte Carlo data. Film measurements in multiple planes around an HDR cervix treatment applicator have shown acceptable agreement with TPS, generally within 4 mm distance to agreement within each plane. Distance to agreement can also be assessed between the multiple film planes (semi-3D analysis).

The EBT3 film-array water phantom has applications as a routine quality control tool, a non-routine commissioning system for new applicators or source models, or as an independent quality audit system, providing semi-3D verification of the actual dose distribution delivered by HDR treatment equipment, in difficult measurement situations.

#### 5. Acknowledgments

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#### 6. References

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