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Linearization of EBT3 film dose response and virtual film dosimetry for SBRT quality assurance

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Abstract

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Linearization of EBT3 film dose response and virtual film dosimetry for SBRT quality assurance

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Abstract. EBT3 film offers high spatial resolution and low energy dependence, making it a suitable choice for quality assurance where high dose gradients are present, such as the case for SBRT. This work presents a simple method to adjust scanner settings so that dose response becomes linear. This linearity eliminates the need to obtain a calibration curve and associated uncertainties in curve fitting. Relative dosimetry can be performed after dose normalization to a reference point. Linearity is also a more robust condition than calibration curve with respect to scanner warm-up conditions, resulting in reduced uncertainty in dose measurement. An in-house developed program reads the film scan and a 2D dose map then constructs both to virtual films using grayscale values. Film intensity value was normalized to dose at reference point. Relative dosimetry was performed by comparing the two resulting images. Patient specific quality assurance was conducted for two SBRT cases. In both plans more than 95% gamma function points passed the gamma criteria of 2%/3mm.

1. Introduction
Stereotactic body radiation therapy (SBRT) uses high dose radiation to target and destroy a well-defined tumour. In such procedures high dose gradients are often present to spare the surrounding healthy tissues from radiation damage. Patient specific quality assurance (QA) is an important step in making sure the planned dose is deliverable and the desired treatment outcome can be achieved [1-3]. Radiochromic film dosimeter such as EBT3 film offers high spatial resolution, near tissue equivalence and low energy dependence, making it a suitable choice for SBRT QA. A typical film dosimetry system requires establishing a calibration curve which converts change in optical density (OD) to absolute dose [4]. This dose response is often non-linear and the calibration curve is sensitive to changes in scanning conditions, thus increasing errors in dose measurement and limiting its use to relative dosimetry. The often lengthy calibration and scanning protocol also discourages its use in routine QA [5]. In this work, a simple method is presented where the scanner settings are adjusted such that scanned film intensity value becomes linear with respect to dose. Subsequently, intensity values can be used directly for relative dosimetry without calculating dose first. Delivered dose at a reference point, represented by its intensity value, can be assumed to equal planned dose - an assumption that can be easily verified with an ion chamber. Delivered dose at other points on the film can then be normalized and compared with planned dose directly. This will greatly simplify the film dosimetry procedure. Another advantage is that as linearity method does not rely on establishing a calibration curve, uncertainties in curve fitting

parameters are eliminated. Linearity can also be a more invariable condition than a calibration curve with respect to variations in scanning conditions, resulting in reduced uncertainties in dose measurement.

2. Materials and methods

2.1. Establishing linearity

One 8'' x 10'' sheet of EBT3 film was cut into 16 strips along the vertical axis. Each strip measures 20.3cm x 1.59cm. The top margin of each film strip was marked with a number from 0 to 1500 in 100 increments indicating the dose (in cGy) to be delivered. The film strips were irradiated in a 6MV photon beam from a Varian Clinac linear accelerator, the machine output of which has been verified using IAEA protocol [6]. During irradiation, each film was placed at a source-to-surface distance (SSD) of 100cm inside a solid water phantom. A 10cm slab was placed on top of the film and at least 10cm slab was placed underneath to provide sufficient backscatter. A field size of 10cm x 10cm was used and each film strip was placed at the center of the field. Film was handled according to TG-55 protocol [7].

An Epson Expression 10000XL flatbed scanner and EpsonScan software were used to scan the films. The glass plates of the scanner were sanitized prior to scanning. Irradiated film strips were placed side by side in increasing order of radiation exposure and taped together at top and bottom to form one sheet, as shown in figure 1. It was then placed inside the scanner with the long axis along the scanning direction to reduce scanner light scattering effect [8]. In the EpsonScan software, transmission mode was selected and all filters and image enhancement options were turned off. The film was scanned in both 48-bit color and 16-bit grayscale mode and saved in TIFF format. All of the red, green, blue channels and the grayscale values were extracted and analyzed separately. A rectangle region of interest (ROI) of 10 pixel x 100 pixel was selected from the center of each strip and the average grayscale value (GSV) was used as the intensity reading for that given dose. An unexposed film was scanned and the ROIs in the same positions were selected to correct for non-uniformity.
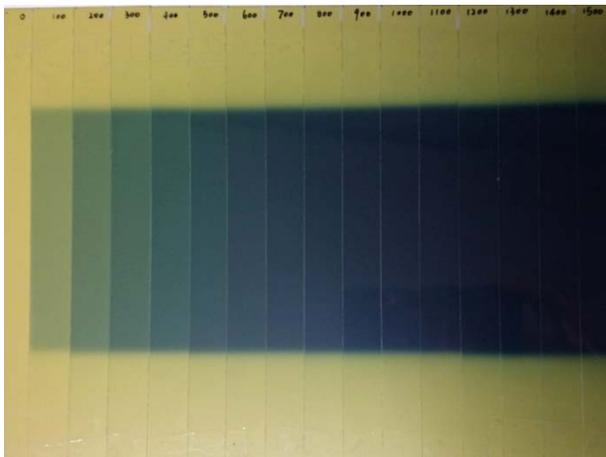

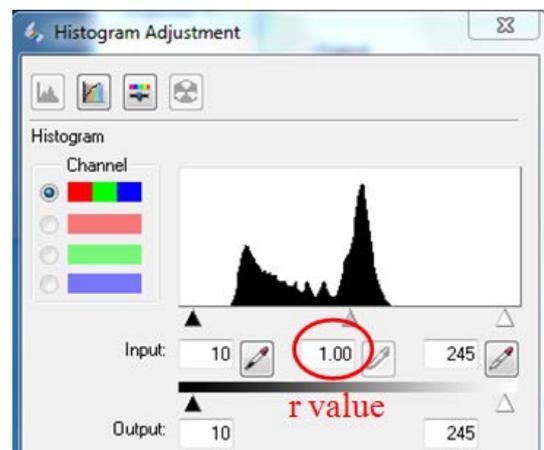**Figure 1.** Calibration film strips prepared for scanning.

Figure 2. Histogram adjustment tab of the EpsonScan software.

Dose response was modelled with a straight line through origin:

$$Dose = a \cdot netGSV = a \cdot (GSV_{exp} - GSV_{unexp})$$

Linearity was evaluated by the R-square value of the fit. In order to linearize the dose response, EpsonScan settings were investigated. We aim to find an adjustment parameter that can be quantified and can alter the shape of the dose response. Preliminary studies had thus narrowed down the choice of

adjustment parameter to the gamma correction value (referred to as the r value in this work) in the histogram adjustment tab of the EpsonScan software, as shown in figure 2. The r value is the equivalent of the inverse of gamma value in image processing. The following r values were tested: 0.5, 1 (default), 2, 3, 4, 5 and 6. A scan was performed after each change of setting. An in-house developed code written in MATLAB was used to select the ROI in each dose region, calculate the netGSV, plot the dose response and compute the R-square value.

In order to test the robustness of linearity with respect to scanner warm-up time, films were scanned immediately after start-up then after 30 minutes and 60 minutes of warm-up time.

2.2. Relative dosimetry for SBRT patient QA
Two SBRT treatment plans of the lung and head and neck region were generated using RayStation treatment planning system. For each plan, one slice was selected from the planning 3D dose distribution and exported as a 2D dose map. The same slice was delivered to an EBT3 film from the same batch as the calibration film in a cylindrical IMRT QA phantom. Irradiated film was scanned using scanner settings established at linearity condition. An in-house developed software loads the scanned film and 2D dose map as two matrices of intensity values. Both matrices were reconstructed to virtual films for display and visual inspection. The software autoregisters the two images based on film dimensions. One point at the edge of the film and one reference point (e.g. ISO center) were selected to normalize the film intensity to dose. The resulting film image can then be compared directly with dose image for relative dosimetry. Criteria for gamma-value analysis was set at 2%/3mm.

3. Results
Auto-histogram option in EpsonScan was selected as it utilizes all available grayscale channels and does not alter linearity. A linear dose response could be established by setting r value to 4. Lower values were insufficient to correct non-linearity while higher values result in heavy compression of intensity output. Figure 3 shows the dose response from each of the color channels as well as the grayscale image. Both grayscale and green channel provide good linearity in the dose range considered. As grayscale image requires only one third of storage space compared to a color image and no extraction of color channel is required, it is the preferred choice for clinical dosimetry. For this reason, all subsequent analysis is based on grayscale image only.
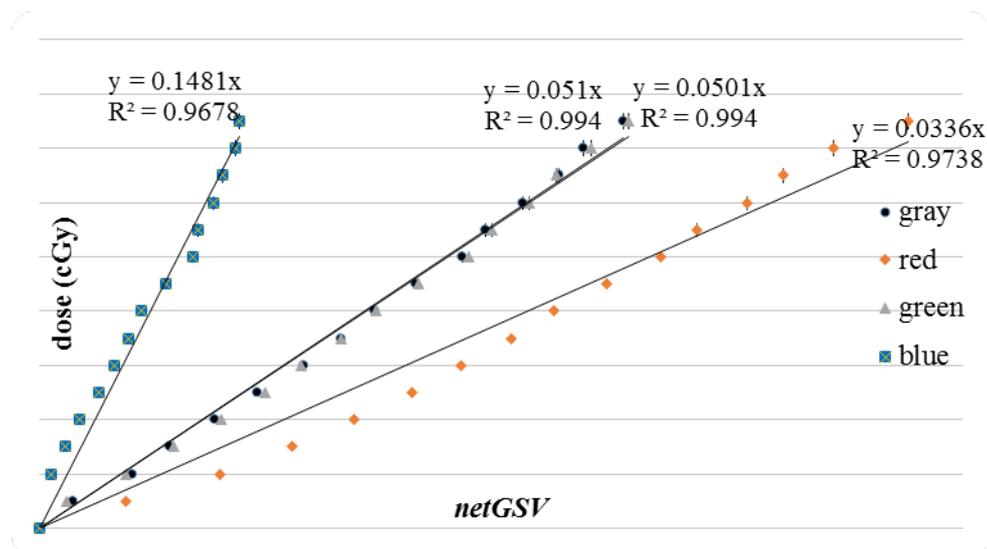

Figure 3. Dose response using grayscale and each colour channel.

When scanner warm-up time was varied from zero through to 60 minutes, the linear coefficient changed slightly due to variations in intensity values but linearity remained the same. In clinical

applications, two main factors affecting dosimetry efficiency are the wait time post-irradiation for the film to develop and the recalibration for each film batch. Future work will test the robustness of linearity with regards to film development time and different film batches.

Linearity method reduces uncertainties in dose measurement in two ways. Firstly, the only parameter of concern is linearity and the linear coefficient is irrelevant. Thus the uncertainties in curve fitting parameters are eliminated. Moreover, with traditional OD method, once a film batch is calibrated, subsequent processing and scanning of the film requires following a protocol aimed at reproducing the condition under which calibration occurred. This is because any change in such condition will result in a shift of the calibration curve, and subsequent dose measurement. With the linearity method, as linearity is insensitive to variations in scanning conditions such as scanner warm up time, any change in intensity values will be self-corrected when intensity values are normalized for relative dosimetry.

Linearity method was applied for SBRT patient QA. Exported dose maps have 1mm spatial resolution. When used for dosimetry analysis they provide detailed dose information which is particularly important in testing high dose gradient area. In both tested plans, more than 95% of gamma function points passed gamma-value criteria of 2%/3mm. The film dosimetry process is straightforward and efficient.

4. Conclusions

It was demonstrated that a robust linearity of dose response for EBT3 film dosimeter up to 15Gy can be established by adjusting scanner settings. As a result, film dosimetry can be conducted without finding a calibration curve beforehand and without regard to scanner warm-up time. An in-house developed software was used to conduct relative dosimetry and proved to provide a convenient way of performing routine QA for SBRT cases with high resolution and accuracy.

5. References

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