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Validation of an ultrasound-guided prostate HDR brachytherapy dose delivery

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Abstract. As part of a recent commissioning process for an ultrasound-guided prostate HDR technique at our centre, a representative dose delivery was validated using Gafchromic EBT3 film dosimetry. Agreement between Oncentra Prostate-calculated plan dose and measured film dose was within 5-10% over most of the 2D film dose planes, except in the regions within 5 mm of the catheter axes. Given the uncertainties associated with the measurement, this result was deemed to be clinically acceptable.

1. Introduction

An ultrasound guidance-based high dose rate (HDR) brachytherapy prostate treatment program has recently been implemented at our cancer centre, with independent point dose calculations of simple geometries using the TG-43 formalism [1] included as part of the commissioning process. These calculations agreed to within 1-2% with the calculated values from the Oncentra Prostate v.4.2.2 treatment planning system (Nucletron BV, NL) throughout most of the treatment volume. Both calculations were based on the TG-43 formalism using the 2D anisotropy function data, so the good observed agreement was consistent with expectation. Greater disagreement (> 10%) was observed in the region within 5 mm of the catheter axes, again as expected [1].

In addition to independent dose calculations, two approaches were contemplated for providing a 3D dose measurement of a sample prostate HDR brachytherapy dose plan delivery in order to validate the planning system in a more clinical situation. The first approach would compare Oncentra Prostate plan dose to measured dose from radiochromic film fixed in coronal and sagittal planes with respect to the ultrasound probe/stepper system and associated treatment catheters immersed in a water tank. EBT3 film is well-suited for this type of validation, as it can be immersed in water for short periods of time with only minor edge perturbations, is effectively dose rate independent [2], has only a slight energy dependence at energies above 100 kV [3], and readily provides near tissue equivalent [4] high resolution 2D dose data for quantifying the dose delivery in representative planes.

The second approach would compare a CT-based Oncentra Brachy v.4.5.2 plan (Nucletron BV, NL, note difference in planning system) with a measured dose distribution in a suitable gel dosimeter to realize a full 3D measurement [5]. This approach requires the use of algebraic reconstruction techniques (ART) to remove the optical artifacts introduced to the 3D image volume by the treatment catheters. The effort to obtain full 3D dose data involves extra validation steps, and will be the subject of a separate report.

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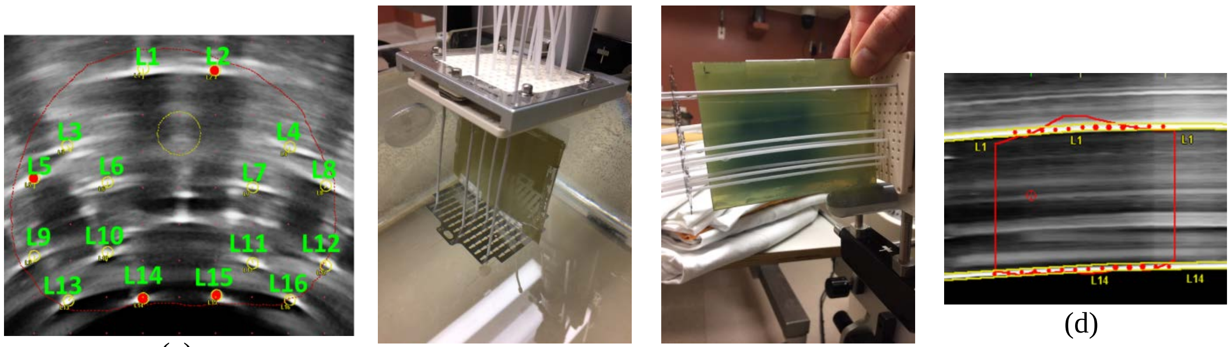
The purpose of this work is to assess the accuracy of the Oncentra Prostate treatment planning system dose calculations using ultrasound image tracked-catheters and Gafchromic EBT3 film (ISP, Wayne, NJ) film for a pseudo 3D evaluation of the dose delivery. This report is part of our ongoing efforts to show the application of 3D and pseudo-3D dosimetry to selected clinical problems and highlight the practical challenges associated with their use.

2. Materials and Methods

2.1. Experimental Setup

The phantom used in this experiment was a 30x30x30cm water tank. Sixteen Proguide 5Fx240mm treatment catheters (Elekta, Atlanta, GA) were inserted into the stepper template in a standard pattern preferred by our clinic (figure 1a) and a typical depth of insertion (see figure 1b). These catheters were then locked in place. In addition to these treatment catheters, four other catheters were inserted in the template with the metal obdurators left in, and a metal template was inserted over the ends of the catheters to provide additional catheter position stability (figures 1b and c). The coronal films were fixed above and below the c3.5 (L3) and e3.5 (L4) needles (figures 1a and b) during plan delivery in the water tank (figure 1b). The sagittal films were attached to the two support catheters in the middle column of the template during delivery and exposed during a separate delivery of the same plan. The position of the sagittal and coronal film planes are as shown in figure 2 (upper right).



(a) (b) (c) (d)

Figure 1. (a) Reference ultrasound image plane showing the needle insertion pattern. (b) Experimental setup showing location of coronal films above and below the L3 and L4 catheters immersed in the water tank, and (c) sagittal films on either side of central axis catheters. (d) Illustration of the catheter tracking on a sagittal ultrasound image slice.

2.2. Delivery Validation

The clinical system used in this experiment consists of a BK3000 ultrasound unit (BK Ultrasound, Peabody, MA) and an OncoSelect stepper system (Nucletron, NL) in combination with the Oncentra Prostate treatment planning system. The 3D ultrasound image used for treatment planning was acquired by immersing the described apparatus in the water tank and imaging according to the standard clinical procedure. Treatment catheters were tracked in Oncentra Prostate (figure 1d), a typical size and position of urethra and prostate were contoured on the ultrasound image, and inverse optimization used to generate a clinically acceptable treatment plan (figure 2). The 15 Gy clinical prescription dose was scaled down to 3 Gy to accommodate the preferred range for EBT3 film dosimetry, and the treatment plan was delivered using a Flexitron remote afterloader (Elekta, Atlanta, GA) with an Ir-192 radioactive source.

Two different calibration approaches were evaluated for their suitability. First, a calibration set of films were irradiated on a Varian TrueBeam linear accelerator (Varian Medical Systems, Palo Alto, CA) under machine reference conditions (6 MV, 10x10 cm^2 field size, 2 cm depth in solid water, 100 cm SAD) to doses spanning the range of 0-9 Gy. Second, three different well-characterized Oncentra Brachy

CT-planned five catheter HDR brachytherapy plans (unpublished work) were delivered to a fixed geometry solid water phantom using the Flexitron remote afterloader unit. Calibration EBT3 films were located 1.0 cm below the central axis plane of the catheters in the solid water phantom (see figure 3a). These plans were developed at our centre specifically for film calibrations in HDR brachytherapy applications (unpublished work). EBT3 film dose readout was accomplished using an Epson 10000XL flatbed scanner (Epson Canada, Markham, ON). Calibrated film dose was compared to Oncentra Brachy dose in 3D Slicer (www.slicer.org) [6].

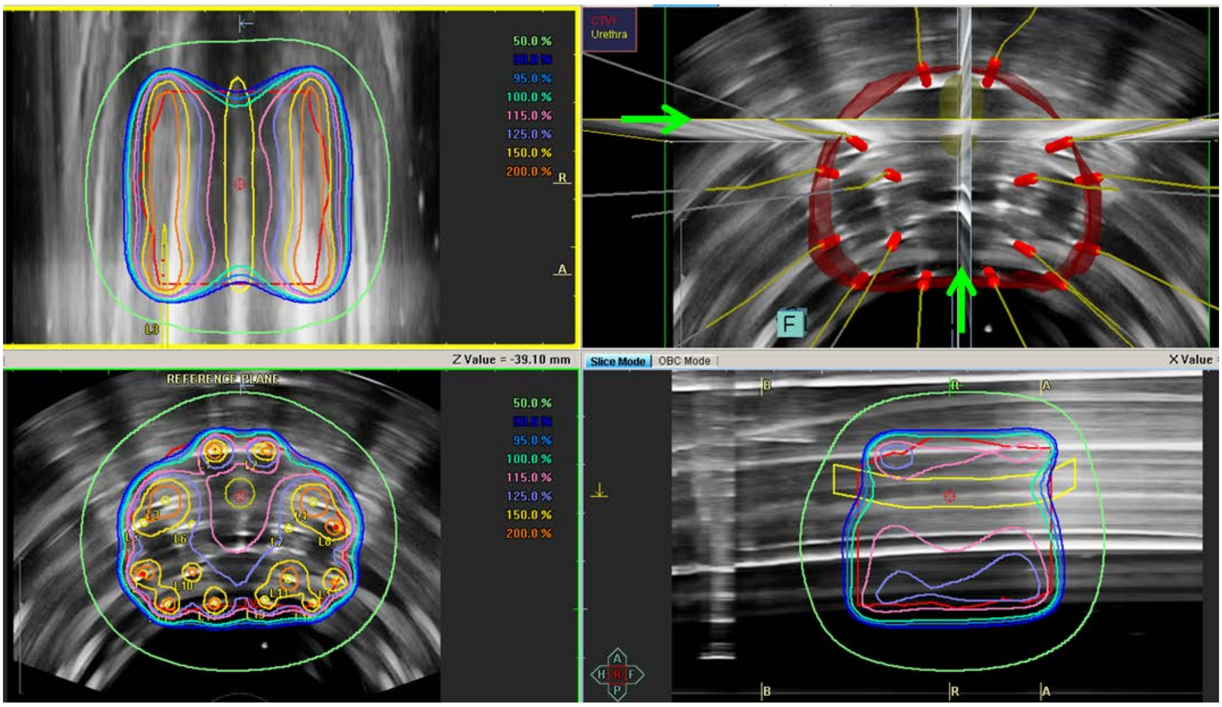


Figure 2. Views of the Oncentra Prostate-calculated dose distribution, with prostate contour drawn in red and urethra in yellow. The 3D image in the upper right shows the planar locations of the coronal and sagittal films. Arrows highlight the 2D slice locations of the film planes.

3. Results

Figure 3a shows a CT image of the HDR brachytherapy catheter geometry in the solid water phantom, along with calculated plan dose. The catheters were fixed in place in machined channels on the surface of a 2 cm thick solid water slab. Figure 3b shows the corresponding overlaid optical density-to dose polynomial fits generated from three simple geometry HDR brachytherapy plan deliveries. The calibrations are labelled as hut, wedge, and circular calibrations in reference to the general shape of the plan dose distributions at the film plane. Overlaid optical density-to-dose calibration curves are shown in figure 3b, with only the data points from the external beam calibration included in the figure, for clarity of comparison.

Figures 4a and 4b show calibrated film dose from the plan delivery. The two coronal and two sagittal films yielded similar results as compared to the calculated plan dose, so only one of each is shown. Figures 4c-4e show representative profile comparisons between calculated plan dose and measured film dose along the 3 image axes, as illustrated by dotted lines in figures 4a and 4b. A gamma evaluation is not shown, as it was deemed to be of limited utility in this application. As seen in the comparisons, the film dose was typically in the range of 5-10% greater than the plan dose in the near-flat regions of dose delivery to the target (i.e. not in close proximity to the treatment catheters).

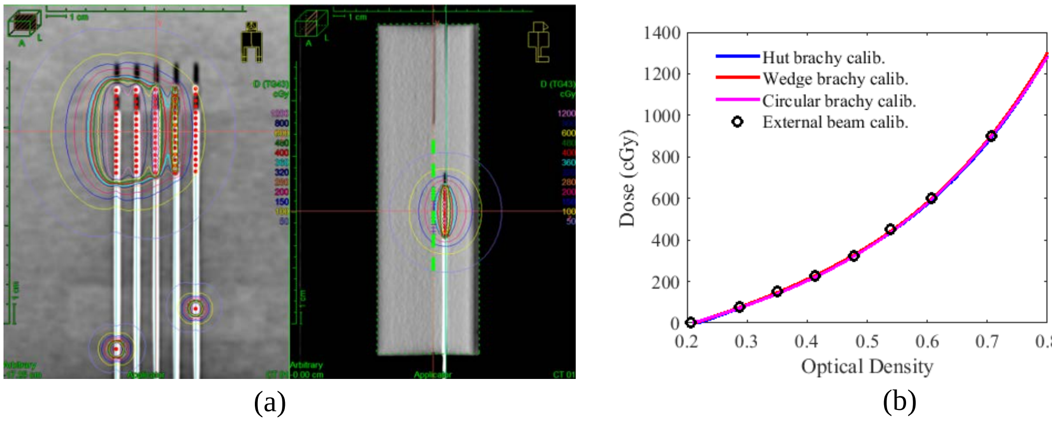


Figure 3. (a) Oncentra Brachy planning system visualization of a five catheter wedge dose distribution plan calculated to a CT-imaged solid water phantom, with EBT3 film located 1.0 cm posterior to the central axis plane of the five catheters (as shown by the green dotted line). (b) EBT3 film optical density-to-dose calibration curves generated from (i) three simple geometry HDR brachytherapy plans, and (ii) a set of varied dose 6 MV external beam single fields delivered to EBT3 film in solid water. Error bars are too small to show.

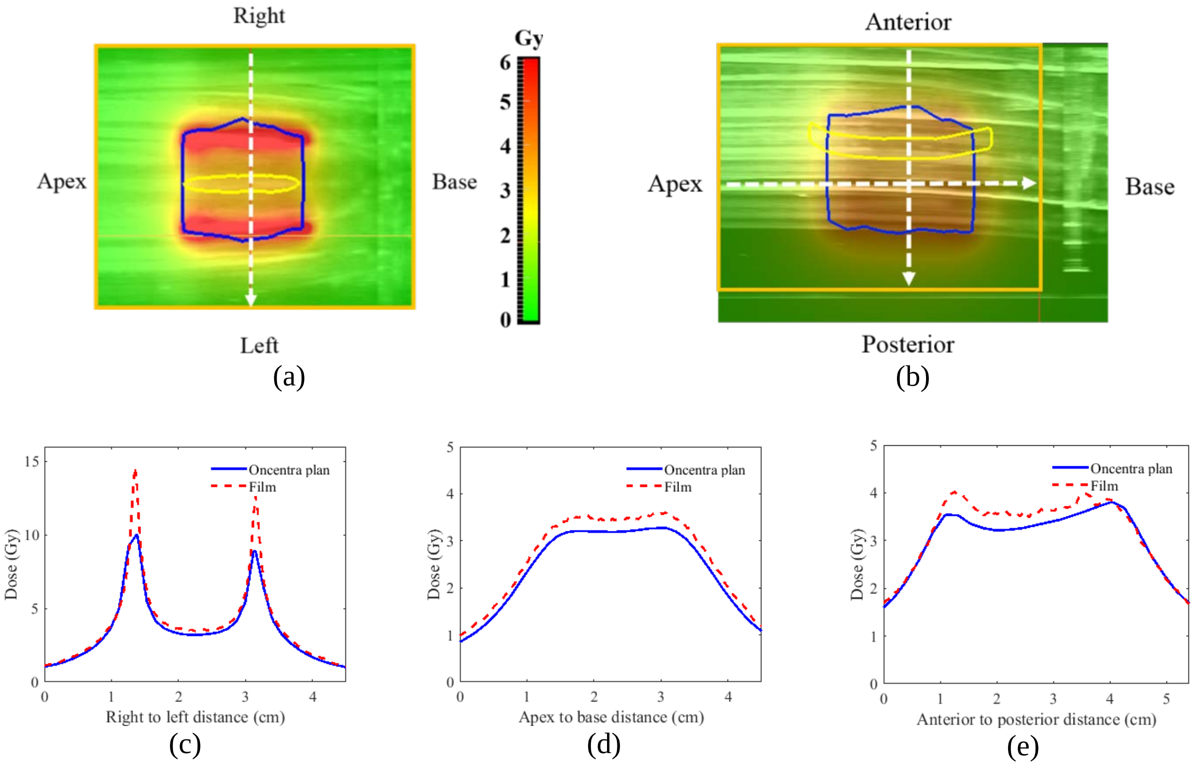


Figure 4. Calibrated film dose from one each of the (a) coronal and (b) sagittal films overlaid on the ultrasound image. The film location is shown in orange, the prostate contour in blue and the urethra contour in yellow. (c) – (e) Dose profile comparisons along the dotted lines shown in (a) and (b).

4. Discussion & Conclusions

External beam radiotherapy-based EBT3 film calibrations have been well-investigated for use in the literature e.g. [7, 8], and our clinical experience with this film dosimeter has yielded similar results. The good agreement between calibration fits shown in figure 3b therefore illustrates that simple geometry HDR brachytherapy plans can also be used for calibration of EBT3 film as long as a proper amount of care is taken to ensuring geometric accuracy in film and catheter placement. This is in agreement with the conclusions reached by Palmer *et al* [2].

The disagreement between measured film dose and calculated plan dose was larger than expected and warrants further investigation, even factoring in the uncertainties inherent to film dosimetry [2, 7, 8]. It is likely that the discrepancy is primarily due to a combination of (a) uncertainty in the film dosimetry, (b) some form of systematic uncertainty in catheter position in the water tank, leading to a 5-10% average increase in dose to the target region, and (c) uncertainty in the treatment planning system calculation. There is a known uncertainty in the template position calibration leading to mis-reporting of catheter position with increasing distance away from the probe surface in the ultrasound image. If a majority of the nearest (to film plane) treatment catheters were located closer to the sagittal and coronal film planes than
reported in the ultrasound image, then an overall increase in delivered dose is possible. The concern is how much of the discrepancy is due to inaccuracy in the planning system dose calculation algorithm.

A few other sources of error have been contemplated. The location of the film in the water tank was not considered to be an issue, as the films were not placed in high dose gradient regions except near the L3 and L4 catheters (figures 3a and 4a). Adjacent plan dose planes were assessed to arrive at this conclusion. Roundoff in treatment delivery time accumulated over multiple dwell positions was assessed as a possible source of error and found to be insignificant. The Ir-192 source strength was well-determined to within 1% via well chamber calibration (corroborated with the calibration report from the manufacturer), and is not deemed to be a significant contributing factor. Transit dose during the delivery could also add an additional source of error, but this was not evident in the comparison between the brachytherapy and external beam calibrations reported in figure 3b, and therefore is not likely to have a significant contributing effect.

Given the practical challenges and inherent uncertainties associated with the validation of ultrasound-guided prostate HDR brachytherapy dose deliveries, and against the backdrop of the reality that this technique is used widely with excellent clinical effectiveness, the results from this work were not deemed to be a deterrent for clinical use of this technique, but rather as an impetus for further investigation. Future work will include a focus on validating the ultrasound imaged-derived catheter positions against an electromagnetic tracking system under development [9].

5. Acknowledgements

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