Towards four dimensional (4D) dosimetry for radiation-therapy

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1. Introduction
The advent of increasingly sophisticated and complex planning and delivery technologies is rapidly transforming the clinical practise of radiation therapy. The last 10 years has witnessed a progression of increasing complexity from conformal therapy to intensity-modulated-therapy (IMRT), to image-guided-therapy (IGRT), and now to four-dimensional (4D) therapy techniques. The latter category encompasses a range of state-of-the-art techniques designed to accommodate or reduce the deleterious effects of breathing and other organ motions on the delivered dose [1]. A major concern is that the pace of innovation in treatment delivery has not been matched by corresponding technological advances capable of verifying these distributions, and the correct implementation of the techniques. In this paper we explore the application of a new 3D dosimetry system to the verification of 4D treatments.

2. Methods
Customised cylindrical PRESAGETM dosimetry inserts [2-4], ~5 cm diameter and 5 cm length, were constructed to fit inside the moving-lung-rod component of the CIRS ‘Dynamic’ Thorax Phantom (figure 1a). The dynamic phantom enables a range of pre-programmed motions, both translation and rotation, to the PRESAGETM dosimeter. The phantom is also compatible with the Varian RPM gating system as dosimeter-insert motion is accompanied by simultaneous simulated breathing motion of the anterior chest wall (note reflective markers in figure 1a). The basic rationale of the 4D verification experiments was to take the phantom containing insert through alternative patient treatment procedures, i) static, ii) simple dynamic, iii) complex dynamic, and compare the delivered dose with that from the ECLIPSE planning system. In the latter two procedures, the phantom was simulated both with and without gating. In each case a similar conformal 7 field plan was created and delivered to the PRESAGETM dosimeter.

Independent validation of selected orthogonal planes of the delivered distribution was achieved with EBT film measurement. The day after irradiation, PRESAGE inserts were scanned in the OCTOPUS™ optical-computed-tomography (optical-CT) scanner commercially available from MGS Research Inc. Slices were reconstructed with in-plane resolution of 0.5 mm, from 180 projections at 1 degree intervals, using an in-house filtered back-projection software. Slice spacing was at 2 mm increments.
3. Results

Corresponding axial and sagittal planes through the measured and calculated distributions for a static delivery are compared in figure 2 a-f. The external circular edge of the extent of the dosimeter is clearly visible in both the PRESAGE\textsuperscript{TM} and EBT distributions, corresponding to where measurements were feasible. The ECLIPSE distribution extends beyond the perimeter of the dosimeter into the surrounding lung. Examination of the axial distributions (figure 2 a-c) reveals good agreement between the PRESAGE\textsuperscript{TM} and EBT film. Both measurements also have general agreement with the ECLIPSE distribution, although the penumbra of the latter is clearly less steep than either measurement. This observation is consistent with previous observations, and indicates incorrect penumbral modeling in ECLIPSE, arising from the fact that the commissioning data was acquired with an IC10 ion chamber with 6 mm diameter. The penumbral blurring in the commissioning data translates through to the calculated dose distribution, and is particularly evident in this instance because the PTV is so small (< 2 cm diameter).

Comparison of the sagittal distributions (figure 2d-f) clearly demonstrates a second distinct source of inaccurate dose modeling in the Eclipse system. Both the PRESAGE\textsuperscript{TM} and EBT distributions show a pronounced extension of dose at the midline of the dosimeter (indicated by yellow arrows). The agreement of both independent measurements provides strong support for the reality of this extension, although it is not present in the dose calculated by ECLIPSE. The interpretation is that this dose is real leakage dose occurring at the leaf matchline. The leakage dose is not modeled in eclipse and is thus not present. For a larger field this leakage could be eliminated closing the X-Y jaws to conform to the target. However, at the time of delivery our ECLIPSE system was only commissioned for fields with jaws > 4 cm minimum opening, creating a region above and below the PTV blocked only by MLC leaves, allowing the observed leakage radiation at the central leaf match-line.
Figure 2. Comparison of isodose lines in the 4D insert measured with PRESAGETM, EBT, and Eclipse. Upper and lower rows are the central axial and sagittal rows respectively. The arrows indicate leakage radiation measured in both PRESAGETM and EBT but not modelled in Eclipse.

4. Conclusions
The development of accurate and convenient dosimetry tools with the capacity to comprehensively verify advanced 4D treatments is an important and urgent goal for radiation therapy physicists. At present, implementation into the clinic is being severely hampered and delayed by the difficulty in adequately verifying these techniques using traditional dosimetry methods. The work presented here represents an important step towards providing a solution. Accurate high-resolution dosimetry has been performed using a convenient and practical system and the results were confirmed with independent measurement using EBT film. Both dosimetry techniques clearly identified and enabled evaluation of two sources of inaccuracies in the dose modeling algorithms of the ECLIPSE planning system; penumbral blurring and leaf-leakage.

5. References
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