Electron dosimetry in the presence of small cavities

Simon Doran\textsuperscript{1,2}, Russell Thomas\textsuperscript{3}, Rachel Hollingdale\textsuperscript{4,5}, John Adamovies\textsuperscript{6}, Andrew Nisbet\textsuperscript{1,5}

\textsuperscript{1}Department of Physics, University of Surrey, Guildford, UK
\textsuperscript{2}CRUK and EPSRC Cancer Imaging Centre, Institute of Cancer Research, Sutton, UK
\textsuperscript{3}National Physical Laboratory, Teddington, UK
\textsuperscript{4}Royal Surrey County Hospital, Guildford, UK
\textsuperscript{5}St Thomas Hospital, London, UK
\textsuperscript{6}Rider University, Skillman, NJ, USA
Simon.Doran@icr.ac.uk

\textbf{Abstract.} Tissue inhomogeneities such as bones or air cavities give rise to significant perturbations of dose during electron radiotherapy. Whilst these can be calculated using a variety of computational methods, accurate experimental verification has hitherto been difficult. In this study, we used 3-D optical computed tomography (CT) dosimetry of PRESAGE\textsuperscript{TM} samples to obtain central-axis depth dose curves and to study the dose distribution around a simple air cavity. Some concerning anomalous results were obtained for the build-up region of the depth-dose curve, which are currently under investigation. However, despite this, the ability to measure rapidly varying dose distributions show great promise.

1. Introduction
Radiotherapy using electron beams has a number of attractive features, chief among which is a much more rapid fall-off of dose with depth than is available when using photon beams. By varying the electron energy and by combining electron and photon irradiations, sophisticated treatments may be given. However, this flexibility comes at a price: tissue inhomogeneities within the volume being treated and, in particular, the presence of air cavities, lead to significant perturbations of deposited dose. Methods to calculate these dose perturbations have been studied for some time [1] and commercial systems have made significant advances [2]. However, accurate experimental verification of complex dose distributions in 3-D has only recently become possible. Whilst it has been recognised for several years that dosimetry of unperturbed electron beams is an excellent way to calibrate and validate 3-D dosimetry scanners [3-4], optical computer tomography (CT) has not, to the best of our knowledge been widely applied to the verification of complex dose patterns around inhomogeneities.

2. Materials and Methods
Dose mapping was carried out using two groups of two PRESAGE\textsuperscript{TM} dosimeters (from separate batches with different sensitivities). The samples were in the form of cylinders of diameter 60 mm and height 60 mm. The first group was irradiated with to 30 Gy at the depth of dose-maximum (D$_{\text{max}}$) using an electron beam of energy 6 MeV from a Varian 2100C/D linear accelerator (Varian Oncology
Systems, California, USA). One of the cylinders was machined with a 1cm diameter and 1 cm length cavity in one of the flat surfaces of the cylinder to determine the difference in the dose distribution in the PRESAGE™ due to the cavity. A 6 cm × 6 cm electron applicator with a 4 cm diameter circle insert was used to provide an electron field at 100 cm FSD. The second set of samples underwent the same procedure using a 9 MeV beam.

Given the relatively small field size of the electron applicator an electron p-type diode (Scanditronix, Uppsala) was used in a water phantom for the depth dose measurements. It was not possible to simulate the cavity in a water phantom, so an epoxy resin water-equivalent phantom (Gammex RMI457, Wisconsin, USA) was employed. Since it was impractical to use the electron diode in such a phantom, an NACP-02 plane parallel chamber (Scanditronix, Uppsala, Sweden) was used for measurements at a number of different depths in the range 0 – 30 mm. Confirmatory measurements had previously verified the consistency in depth-dose measurement between diode and plane parallel chamber beyond the build up region.

The PRESAGE™ samples were placed on the treatment couch with the centre of the sample aligned with the cross hairs of the linear accelerator, and FSD was set to 100 cm at the surface of the sample. After irradiation, PRESAGE™ samples were imaged with the University of Surrey optical CT scanner, using the following parameters: field-of-view 64.5 mm, projection image matrix size 256×256, acquisition time 24 mins. for 400 projections over 180°, reconstruction matrix size 256×256, nominal in-plane resolution (0.25 × 0.25) mm2.

**Figure 1:** Comparison of diode and PRESAGE™ results along the central axis for the sample with no air cavity. The poor agreement of the diode and PRESAGE™ measurements between 5 and 15 mm is currently under investigation. The rapid fall-off of the PRESAGE™ data below a depth of 5 mm is well understood, being indicative of image artefacts occurring at the sample-matching liquid interface at the top of the sample.
Figure 2: Optical CT data from the second set of two samples, irradiated with a 9 MeV electron beam: (a) sample with no inhomogeneity; (b) sample with an air cavity. In each case, the main graphic is the surface plot of a longitudinal cross-section through the sample approximately 2 mm off-centre. Unfortunately, an optical artefact (possibly caused by a spurious reflection from a metallic part of the apparatus) spoils the images in (a), so we attempted to avoid this where possible during the analysis.
Two methods for increasing the signal-to-noise ratio of the measurement were tested and found to produce results of similar quality: (i) the fact that the electron dose was axially symmetric was exploited to perform a radial averaging procedure; (ii) since the dose distributions were expected to be smooth, a 3-D median filter of kernel size $7 \times 7 \times 7$ voxels was applied.

Figure 3: Comparison of data from the two 6 MeV samples: (a) depth doses averaged over annular regions of different sizes along the central axis — see main text for further explanation — together with data measured in a solid water phantom using an ionisation chamber; (b) dose at radial distance of 12.7 mm from the centre of the sample, at which point (away from the influence of the cavity) the two distributions are expected to be similar.
3. Results and Discussion

Figure 1 compares diode measurements in a water tank with the depth-dose curve obtained along the central axis of the 6 MeV sample without the air cavity. The depth values for the PRESAGE™ measurements were scaled to their water equivalents by multiplying by the ratio of the densities. The agreement beyond $D_{\text{max}}$, is extremely good. The deviation of the optical CT results from those expected in the build-up region of Figure 1 is currently unexplained and a concern, but it is interesting to note that Figure 2(b) of [5] demonstrates a very similar effect using MRI-based polymer gel dosimetry. Repetition of all the experiments is planned.

Figure 2 shows a visualisation of the dose distribution from a longitudinal plane near the centre of the dosimeter for each of the two 9 MeV irradiations. We did not analyse the central plane because the optical artefact illustrated in Figure 2(a) was worse there. It is clear that the presence of the air cavity causes a major perturbation in the field, with the dose deposited immediately distal to the cavity being some 20 – 40% higher than that at an equivalent position the other sample. These results match well with the distributions predicted in Figure 4 of [1], but which could not, at the time of that publication, have been verified experimentally.

For a more quantitative comparison, Figure 3(a) shows PRESAGE™ data for both 6 MeV samples and the matching parallel plane ionisation chamber data. The lower curves (large and small black triangles) demonstrate that, in the sample with no cavity, the PRESAGE™/optical CT measurements agree extremely well with the ionisation chamber. It is evident from Figure 2 that the dose varies very rapidly with radial distance from the centre of the distribution. In order to compare the ionization chamber readings with the 3-D dosimetry results, we need to integrate the 3-D results over a range of radii corresponding to the size of the ionization chamber. The upper curves of Figure 3(a) depict the depth dose that results from integration over different ranges. Of interest are both the change in relative dose at $D_{\text{max}}$ and the shift in $D_{\text{max}}$, both of which can be understood by looking at the distribution in Figure 2. It will be seen that an excellent match with the ionization chamber reading is obtained when we integrate over the range $0.5 < r < 5.8$ mm. This range is in reasonable agreement with [6], which found the “effective collecting radius” of a set of 6 NACP chambers to vary between 5.23 and 5.61 mm.

4. Conclusion

3-D dosimetry using optical CT of PRESAGE™ samples has the potential to be an excellent method for looking at rapidly varying electron dose distributions around inhomogeneities. However, this study is a work in progress and further experiments are needed to obtain reliable results.

References

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