**True-3D scans using PRESAGE™ and Optical-CT: A case study in proton therapy**

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1. Introduction

MRI and laser-scanned optical-CT are widely reported as being three-dimensional readout methods for gel dosimetry. This is, of course, technically correct. However, in practice, it is normal to acquire only a limited number of slices in the third spatial dimension. In MRI, this is because true-3D pulse sequences for fast, quantitative $T_2$-mapping are not widely available. If high dose-resolution is acquired, one might expect to acquire of order 8 slices in a scan-time of 40 minutes [1]. Laser-scanned optical-CT acquires slices one at a time and a recent publication [2] states that 50 slices can be acquired in an acquisition time of 8–10 hours (i.e., 10–12 minutes per slice).

If true-3D information is required, with high resolution in all three spatial dimensions, then CCD-based optical-CT systems offer a potential advantage. The individual projections that comprise the raw data of such scans are inherently two-dimensional and, upon reconstruction, lead to high-resolution, true-3D images.

This preliminary study of proton irradiation of a PRESAGE™ transparent solid plastic dosimeter is presented as a case study to illustrate the potential of a true-3D approach.

2. Proton beam therapy

Experience with conformal radiotherapy has shown that, even with the many modern beam-shaping techniques available, local tumour control cannot be achieved for some radioresistant tumours. Furthermore, even for radiosensitive tumours, one cannot always achieve the desired conformity because of the unavoidable associated dose to nearby critical body structures. Irradiation with heavy charged particles (such as protons or heavier ions such as carbon) offers a potential therapeutic benefit for two reasons. First, there is an improved control over the dose distribution due to a rapid rise and fall-off of the dose deposited around the Bragg peak. Second, the high linear energy transfer (LET) radiation leads to an improved biological (cytotoxic) efficiency.

Previous gel dosimetry studies of proton irradiations have been performed using MRI in conjunction with Fricke [3] and polymer [4] gels and using FT-Raman measurements [5]. However, to
our knowledge, this is the first published account of the irradiation of a PRESAGE™ dosimeter with a proton beam and the first true-3D measurement of a complex proton dose distribution.

3. Materials and methods

Two samples of the transparent solid plastic dosimeter PRESAGE™ were prepared in the form of right cylinders of diameter 60 mm and height 60 mm. These were irradiated at the 62 MeV proton beam facility of the Douglas Cyclotron, at the Clatterbridge Centre for Oncology (Wirral, Merseyside, UK) — see Figure 1. The first sample was irradiated three times, using an unmodulated beam, collimated to a 12 mm-diameter circular cross-section. The beam was applied for different durations, such that estimated doses of 4, 8 and 12 Gy were applied at the Bragg peak. This allowed us to verify in a single sample both the linearity of response of the dosimeter and its response characteristics as a function of LET. The second sample was irradiated four times with the proton beam modulated and collimated to a 12 mm × 12 mm square field. The four different irradiations used beam blocks in a number of different ways: (i) a 3 mm Al half-field block at the exit of the collimator (Figure 1b); (ii) the same block fixed to the surface of the dosimeter; (iii) a 40.9° Al wedge and (iv) a 16.1° Al wedge (Figure 1c), both fixed to the dosimeter. Figure 1d shows a digital photograph of the sample approximately 30 minutes post-irradiation, taken from above.

Optical-CT scanning of the sample was performed using the equipment described in [6], but using a mixture of dibutyl and dialyl phthalates, with refractive index n = 1.503, as a matching liquid. For the first sample, 1000 raw projection images of dimension 448 × 256 were acquired with 4 signal averages, over a period of 3 hrs and 50 minutes. These were reconstructed onto square matrices of 224 × 224 pixels, giving an in-plane nominal pixel resolution of (0.36 × 0.36) mm² and slice thickness of 0.18 mm. The corresponding parameters for the second sample were: raw projection matrix size 384 × 160 pixels, 1000 projections with 4 averages, reconstruction onto 192 × 192 pixels, in-plane resolution...
(0.42 × 0.42) mm² and slice thickness 0.21 mm. An isosurface plot was created using the *slicer3* tool in IDL.

4. Results and discussion

Figure 2 shows the data obtained from Sample 1. Images of excellent quality are obtained, despite the high spatial resolution. The small slice thickness allows the detail of the Bragg peak to be visualised with unprecedented detail. Each point on the curve represents the mean of a circular region (~700 pixels) of interest corresponding to the beam location. Figure 3 illustrates the quality of 3-D data available using the technique.

**Figure 2.** Results of calibration experiment. The main graph illustrates the Bragg peak for the three beams, while the inset shows a typical slice through the 3-D dataset.

**Figure 3.** Results of experiment to map the sample irradiated with a modulated beam
5. References

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