Optical CT scanning of PRESAGE™ polyurethane samples with a CCD-based readout system

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1. Introduction
Since 1996 [1], it has been clear that optical computed tomography (CT) represents a viable alternative to MRI scanning of dosimeter gels. Considerable progress has been made in the development of laser-based scanning systems, particularly by MGS Inc. [2], which markets a commercial system, and by Oldham et al [3]. An alternative means of performing the optical CT experiment was introduced in 1999 by Wolodzko et al [4] and Doran et al [5,6], with further work by Jordan et al [7]. Although both methods allow high-resolution images to be obtained, the CCD-based method gives multiple slices in a time similar to that required for a single slice on a laser-based system, allowing the generation of full 3-D datasets in a realistic scan-time. However, a consequence of this “parallel acquisition” is the introduction of more potential sources of artifact, particularly due to refraction, as shown below.

This abstract demonstrates the resolution capabilities of the CCD scanner under ideal circumstances and describes the first CCD-based optical CT experiments on a new class of dosimeter, known as PRESAGE™ (Heuris Pharma, Skillman, NJ).

2. Scanner capability under ideal conditions
The optical CT scanner used was a variation of that reported in [6], with light source modified to be suitable for the imaging of PRESAGE samples. As a demonstration of the scanner’s inherent performance, a high-contrast phantom was created. Similar to the “needle” phantoms of Oldham et al [3], this consisted of three strands of copper wire, bent arbitrarily to give a three-dimensional structure. Figure 1a shows that sharp, high-quality projections are obtained. Minor scratches on the back-wall of the “aquarium” lead to imperfections in the raw data, but as previously described [6], these can easily be corrected for. 402 projections, each of 512 × 512 pixels were acquired in approximately 15 minutes and rebinned to 256 × 256 (Nyquist criterion).

For each slice, a sinogram of the form of figure 1b was created. In optical CT (as compared with MRI) signal-to-noise ratio is not an issue when using a high-quality camera. The key measure of image performance is the signal-to-artifact ratio. In this example, the apparent stripes in the sinogram background led to a ring artifact, but the effect was at such a low level that further processing was deemed unnecessary. The main artifacts in the data of figure 1c, at a level of approximately 3% of the...
mean signal from the wires, were streaks of “negative intensity” joining the three wires. The wires are effectively infinite attenuators, so any projections in which light passes through both wires do not give adequate information to reconstruct the image correctly. In the case of gel dosimetry, this situation does not arise. For this ideal object, a clean 3-D dataset is achieved and a rendered view is shown in figure 1d.

Figure 1. Optical tomography data from an “ideal” high contrast object: (a) single projection image; (b) sinogram obtained from 402 projections; (c) reconstructed image of a single plane of data; (d) 3-D rendered image of the entire dataset.

3. Scanning the PRESAGE™ dosimeter

PRESAGE is a solid dosimeter, based on a clear polyurethane combined with the leuco-dye leucomalachite green [8]. The dosimeter is designed to absorb strongly at a wavelength of 632 nm in order to be compatible with a He:Ne laser-based scanning system. PRESAGE has a number of potential advantages over both conventional polymer gels and Fricke gels. These include: (i) PRESAGE is a robust solid and needs no container; this makes optical matching and general handling much easier. (ii) Irradiated regions of PRESAGE exhibit negligible diffusion of the coloured medium. (iii) Provided the sample is kept away from light, except while scanning, it appears highly stable.

We have performed a series of exploratory optical-CT measurements to investigate the feasibility of using PRESAGE in our CCD scanner. A 70 mm-diameter cylinder of PRESAGE was irradiated using a purpose-built lead collimator 67 mm thick, in which was drilled a square grid of holes each 2 mm in diameter and separated by 10 mm. A nominal dose of 30 Gy was given to the top of the lead collimator, with the PRESAGE sample placed underneath. This led to a square pattern of 2 mm irradiated columns in the dosimeter. These were visible optically when looking almost end-on to the flat face (i.e., through an irradiated region of approximately 50 mm). However, with the sample in the matching liquid and looking at right angles to the columns, individual columns were resolved by eye only with some difficulty if at all. Thus, this scenario represents a moderately challenging one for optical dosimetry.

Figures 2a and 2b show the importance of obtaining exactly the right refractive index for the matching medium. For the projection of figure 2a, the medium was prepared with the proportions of its constituents calculated for $n = 1.499$, which was the refractive index for the PRESAGE estimated by the manufacturer. A very thick edge artifact is observed. By contrast, when $n$ is increased to 1.502, this effect disappears almost entirely [6]. In these preliminary observations, projections of the interior of the dosimeter are non-uniform, with swirling patterns. Although visually, the dosimeter gel appears entirely clear with few imperfections, we believe that, internally, there are slight variations in the refractive index of the polymer, causing light to be refracted away from a parallel path. Thus, some regions of the projection screen receive less light than expected, whereas others have several rays superimposed generating higher signal intensity. The differences in contrast here are at least as great as the differences caused by the radiation-induced absorption and thus have the potential to cause image artifacts.
Figure 2. (a) Projection of a cylindrical PRESAGE gel with matching liquid having $n=1.499$ (estimated); (b) corresponding projection with a matching liquid having $n=1.502$ (estimated).

Figure 3a shows the result of imaging a dosimeter irradiated using the lead collimator as described above. It can be seen that, although the signal-to-artifact ratio in this scan is very much poorer than in the ideal example of figure 1, nevertheless the 2-mm spots are well visualised. Moreover, the circular structure of each spot is well defined, with a radius of approximately 6 pixels, indicating a true spatial resolution of approximately 300 µm. Figure 3b demonstrates the result of a $2.7 \times 2.7$ cm² square-field irradiation, with a dose of 30 Gy to the top of the dosimeter.

Figure 3. (a) CCD tomography scan of PRESAGE dosimeter irradiated using the lead collimator described in the text. The double ring artifact in (a) occurs because the sample was imperfectly matched during this scan.

4. Conclusions

Optical-CT scanning of PRESAGE™ dosimeters offers considerable promise for the future. The attractive physical properties of the polymer, particularly its solid nature, lack of diffusion effects and stability make it more convenient to use than previous gel formulations. Problems due to small variations in refractive index remain to be overcome, but initial results indicate that image resolutions of the order of hundreds of microns are easily within reach.
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