Radiological attenuation properties of normoxic polymer gel dosimeters

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1. Introduction

Since the development of normoxic gels [1] several others have been evaluated for dose response and spatial stability with MRI [2,3]. Tetrakis (hydroxymethyl) phosphonium chloride (THP) has been used as an oxygen scavenger [3] in MAGAT and PAGAT polymer gel dosimeters. X-ray CT has been used as an evaluation tool to measure dose response and dose distributions of irradiated polymer gel dosimeters [4–7]. In this work the radiological attenuation properties of the PAGAT and MAGAT normoxic polymer gels are investigated as part of a feasibility study in using x-ray CT as an evaluation tool for normoxic polymer gel dosimeters.

2. Method

The components used for preparation of MAGAT polymer gel were 8% gelatin, 9% methacrylic acid, 10 mM THP and 83% water. Those used for PAGAT were 5% gelatin, 3% Bis, 3% acrylamide, 10 mM THP and 89% distilled water. The method described by De Deene et al [2] was followed in preparing both the MAGAT and PAGAT polymer gel dosimeters. Parallel walled polystyrene cuvettes with a path length of 1.0060 ± 0.0002 cm and wall thickness of 0.1060 ± 0.0002 cm and plastic screw top vials of length 5.6 cm and diameter 2.4 cm were used for radiological attenuation and CT dose response measurements respectively. The gels were irradiated to doses up to 40 Gy in a previously calibrated 60Co Gammacell 200 [8].

The attenuation measurements were carried out with a similar set up used previously [6]. Normalisation and background counts were obtained with and without the source in the radiation path. Radiation counts were then obtained with empty cuvettes in the radiation path to correct for the attenuation due to cuvette walls. For calculation of linear attenuation coefficient of deionised water and gel, radiation counts were obtained through cuvettes filled with de-ionised water and gel by increasing the number of cuvettes in steps of 1 to a total number of 5. The corrected value of log of attenuation counts, y, was plotted against radiation path length through water, t. The linear attenuation coefficient was calculated as the gradient of the linear fit of the corrected value of radiation counts plotted against radiation path length through the polymer gels.
CT imaging was performed in water filled cylindrical Perspex phantom of a similar design to that used previously [5]. Images were acquired with a Toshiba Aquilion CT scanner with 135 kVp with a tube current of 400 mA and exposure time of 1000 ms. The averaged water image was subtracted from the averaged vial image to remove artefacts and the average CT number computed using modified software [9] coded in MATLAB™. CT numbers were obtained by taking the mean value over a region of interest (number of pixels) in the subtracted image.

3. Results and discussion

Figure 1a is the log attenuation curve for the unirradiated PAGAT and MAGAT polymer gel dosimeters. Figure 1b shows the change in linear attenuation coefficient with absorbed dose for the dosimeters fitted with a monoexponential curve.

![Figure 1a](image1a.png)  
![Figure 1b](image1b.png)

**Figure 1.** (a) Log attenuation curves for the unirradiated gels and (b) variation of linear attenuation coefficient with absorbed dose.

Variation in CT numbers calculated from linear attenuation measurements for both PAGAT and MAGAT polymer gels are shown in figure 2. Both calculated and measured CT numbers followed a similar pattern and were fitted with a biexponential curve.

![Figure 2a](image2a.png)  
![Figure 2b](image2b.png)

**Figure 2.** Variation of CT numbers with (a) absorbed dose and (b) linear attenuation coefficient.
The CT numbers obtained from attenuation measurements were found to be greater than that obtained with the CT scanner for both PAGAT and MAGAT polymer gels. The uncertainties in calculated and measured CT number were calculated using the Taylor expansion and was found to be $< \pm 1H$ and $< 0.1H$ respectively. The results obtained agree with previous results [6]. In a CT scanner, the value of $\mu$ for each pixel is calculated with the assumption that the radiation transmitted is monoenergetic. The beam, however, is heterogenous and the linear attenuation coefficient is not a linear function of absorbed dose due to the heterogeneity of source used in CT scanner. For polychromatic radiation the attenuation of homogenous object is not strictly proportional to its thickness [10]. The linear attenuation coefficient decreases with increase in energy. Since the linear attenuation coefficient has a linear relationship with CT number [11], a decrease in the attenuation coefficient leads to a decrease in CT number explaining the decrease in the CT numbers obtained from the CT scanner when compared to those calculated from attenuation measurements.

Table 1 shows the linear response range and H-dose sensitivity for both PAGAT and MAGAT polymer gels. MAGAT had a linear dose response up to a dose of 10 Gy while the PAGAT had a linear dose response up to 15 Gy. The H-dose sensitivity for the measured $H$ obtained from CT scanner was $(0.8502 \pm 0.0842)$ HGy$^{-1}$ and $(0.3078 \pm 0.0267)$ HGy$^{-1}$ for MAGAT and PAGAT respectively. The H-dose sensitivity obtained from the calculated CT number from attenuation measurements was found to be $(1.1003 \pm 0.0647)$ HGy$^{-1}$ and $(0.34238 \pm 0.0099)$ HGy$^{-1}$ for the MAGAT and PAGAT polymer gels. It was found that the CT-dose sensitivity for both PAGAT and MAGAT were greater for the attenuation measurements when compared to those obtained from CT scanner.

Figure 3 shows the variation in CT number with linear attenuation coefficient of PAGAT and MAGAT polymer gel dosimeters. The CT numbers varied linearly with linear attenuation coefficient for both the polymer gels as expected. For the MAGAT gel the linear fit had an $r^2$ value of 0.99519, $p < 0.0001$ and standard error of 0.60448. The PAGAT polymer gel had a linear fit with $r^2$ value of 0.99519, $p < 0.0001$ and standard error of 0.00005.

| Table 1. Linear response range and dose sensitivity for PAGAT and MAGAT polymer gels. |
|---------------------------------|------------------------------|-------------------|-------------------|-------------------|
| Attenuation                    | CT                           | Attenuation       | CT                           |
| Linear response                | 15 Gy                        | 15 Gy             | 10 Gy                        | 10 Gy             |
| Dose sensitivity [HGy$^{-1}$]   | $0.34 \pm 0.01$              | $0.31 \pm 0.03$   | $1.10 \pm 0.065$            | $0.85 \pm 0.084$  |

4. Conclusions

The calculated and measured linear attenuation coefficient and the CT numbers increased with absorbed dose for PAGAT and MAGAT polymer gels. The CT-dose response from both measured and calculated CT numbers was found to be linear up to 15 Gy for PAGAT and 10 Gy for the MAGAT polymer gels.
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