Quantitative evaluation of polymer gel dosimeters by broadband ultrasound attenuation

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Abstract. Ultrasound has been examined previously as an alternative readout method for irradiated polymer gel dosimeters, with authors reporting varying dose response to ultrasound transmission measurements. In this current work we extend previous work to measure the broadband ultrasound attenuation (BUA) response of irradiated PAGAT gel dosimeters, using a novel ultrasound computed tomography system.

1. Introduction
Ultrasound has been shown to have the potential to evaluate gel dosimeters [1] due to changes in the measurement of velocity, attenuation and frequency dependent attenuation [2-6]. Here, we evaluate a measure of the linear increase in ultrasound attenuation with frequency, termed broadband ultrasound attenuation (BUA [7]), using a novel ultrasound computed tomography system.

2. Method and Materials
2.1. PAGAT gel preparation and irradiation
A batch of PAGAT gel was manufactured based on the Venning et al [8] formulation with the THPC (Tetrakis Hydroxymethyl Phosphonium Chloride) [9] concentration increased to 8 mM [10] under normal atmospheric conditions. Once prepared, the gel was poured into 150 ml cylindrical shape PET (Polyethylene terephthalate) containers of 10 cm height and 4.5 cm diameter and refrigerated at 4°C for about 24 hours prior to irradiation. Each gel was then located in a water tank [11] and irradiated to various doses from 2 to 30 Gy, at the depth dose of 1.5 cm, 100 cm SSD and 2x2 cm² field size utilising a 6 MV photon beam delivered by Linac 600 CD. The irradiated gels were again refrigerated at 4°C for about 24 hours before imaging [12].

2.2. Imaging technique and data collection
The ultrasound computed tomography (CT) system used to scan our samples comprises of two co-aligned 5 MHz, 128 element linear-array transducers; one serving as transmitter, the other as receiver. Only 64 elements of each transducer were utilised, totalling 128 elements, the maximum operational capacity of the Olympus Omniscan unit utilised. Scans were performed whereby the transducers were fixed in position whilst the sample was rotated in one degree steps using a programmed robotic arm (figure1). For each scan position an excitation pulse was applied sequentially to each transmitter transducer element (Tn) via the Omniscan unit and associated TomoView software. The propagated
ultrasound signal for detected by the corresponding co-aligned receive transducer element (Rn); hence T1-R1, T2-R2, T64-R64. The total number of acquired signals per slice is 23040 resulting from 64 transmissions per projection times by 360 (number of projections).

Figure 1: Ultrasound transmission computed tomography scanner.

To determine broadband ultrasound attenuation (BUA), two sets of measurements were recorded; one taken for the gel sample and the other one for the reference material, chosen to be non-irradiated gel. For each transmitted signal, the BUA value was measured through four steps:

1. For each individual transmitted signal (time domain signal), the time-portion of signal which includes the maximum signal amplitude was extracted for both sample (irradiated gel) and reference (non-irradiated gel).
2. Fast Fourier transforms of these two extracted portions were calculated and the attenuation at each individual frequency calculated using equation 1, where A_{Ref} and A_{sam} are the signal amplitudes of the reference signal and amplitude of the sample respectively.
3. Attenuation was plotted against frequency.
4. For a defined and consistent frequency range where attenuation increased approximately linearly with frequency, BUA was calculated as the slope of ultrasound attenuation versus frequency using a least square fit.

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\text{Attenuation (f)} = 20 \log \left( \frac{A_{\text{Ref}}(f)}{A_{\text{sam}}(f)} \right) \text{ (dB)} \quad [\text{Eq 1}]
\]

The measured BUA values corresponding to each of the 64 transducer element pairs at each projection angle, were transferred into a two dimensions matrix (64 × 360) termed a sinogram, describing BUA data as a function of distance along the projection (transducer pair signals) and projection angle. The matrix was transformed into a two dimensional BUA image using the iradon function in Matlab (Mathworks Inc).

Ultrasound frequency spectra for a) reference (non-irradiated gel) signal amplitude, b) sample (irradiated polymer gel) signal amplitude and c) attenuation are shown in figure 2. In this work, BUA values were obtained over a frequency range from 2.5 MHz to 6 MHz.
3. Results and Discussions

Figure 3, shows an irradiated sample and reconstructed BUA map for one slice through one batch of gel, irradiated with a 2x2 cm square field at a specific dose rate of 30Gy. The image reconstruction procedure was repeated for each batch of the gel irradiated at different doses. From the reconstructed images, a consistent region of interest (located about the centre of the image) was specified, with average and standard deviation BUA values calculated.

![Figure 3: (a) PAGAT gel sample irradiated with 2x2 cm square field at 30 Gy; (b) reconstructed BUA map](image)

The variation of the BUA values with absorbed dose is shown in figure 4, noting that they show a dependence upon radiation dose. Further investigation is required of the dose dependency of BUA values at low doses.
4. Conclusion
BUA computed tomography has been shown to have potential for measurement of the dose response of PAGAT gel dosimeters. Further work is required to examine the non-linear response at doses below 10 Gy and to investigate other polymer gel compositions [13-15].

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6. References
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