Measurement of a PAGAT gel dosimeter by ultrasound computed tomography

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Abstract. In this work we used a 3D quantitative CT ultrasound imaging system to characterise polymer gel dosimeters. The system comprised of two identical 5 MHz 128 element phased-array ultrasound transducers co-axially aligned and submerged in water as a coupling agent. Rotational and translational movement of the gel dosimeter sample between the transducers were performed using a robotic arm. Ultrasound signals were generated and received using an Olympus Omniscan unit. Dose sensitivity of attenuation and time of flight ultrasonic parameters were assessed using this system.

1. Introduction
Recent years have seen the development of gel dosimetry for radiotherapy purposes. Following irradiation, the physical properties of these radiosensitive gels undergo changes that can be measured using various medical imaging equipment [1-21]. Traditionally this imaging has utilised either optical computed tomography (CT) [1, 2] magnetic resonance imaging [3-5] or x-ray CT [6, 7]. Previous studies have examined the feasibility of ultrasound based CT to study dose response in PAG dosimeters [8-11]. Here we extend that previous work on polymer gel dosimeters utilising a new ultrasound scanner design. The sensitivity response was investigated through measuring ultrasound attenuation coefficients and ultrasound time of flight in irradiated PAGAT gel [12, 22] dosimeters.

2. Method and Materials
2.1. PAGAT gel preparation and irradiation
A batch of PAGAT gel was manufactured based on the Venning et al [10] formulation with the THPC (Tetrakis Hydroxymethyl Phosphonium Chloride) concentration increased to 8 mM [11] 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 irradiated to various doses from 2 to 30 Gy using a Gammacell 200 (Co-60) source. Irradiated gels were again refrigerated at 4°C for about 24 hours before imaging.
2.2. Imaging technique

The equipment required to set up the ultrasound CT system was an Olympus Omniscan unit, two 5 MHz 128 element phased-array transducers, Olympus TomoView software (to define beam configuration), Motoman HP6 mounted robotic arm (with 6 degrees of freedom), microcontroller, water tank and transducer fixture.

In our ultrasound CT system the phased array transducers are mounted and aligned in parallel on a frame and submerged in a water tank (figure 1). One transducer serves as the transmitter and the other as the receiver. Scans were conducted with the transducers fixed in position while rotational and translational movement of the gel dosimeter sample between the transducers was performed using a programmed robotic arm. The lateral ultrasound scan of the sample was performed by exciting individual transducer elements from first to the last without any need to displace the transducer and subsequently a projection data set was taken. After the completion of a single scan, the sample was rotated at an angle increment of one degree and the next projection was recorded. It should be noted that the Omniscan MX equipped with the PA32128 acquisition module is capable of transmitting and acquiring with 128 individual elements and for this reason only 64 elements could be allocated for each of the two transducers; this was accomplished by using a splitter connector.

![Figure 1: Ultrasound transmission CT](image)

All signal acquisition parameters such as digitising frequency, data sample size, signal rectifications were configured through TomoView software. The rotational position of the sample and ultrasound transmission/reception were synchronised via a microcontroller.

2.3. Data collection and image reconstruction

Signal digitisation was performed at 25 MHz and 12 bit resolution. For 64 transmission elements acquired through 360 projections created 23040 ultrasound signals in total. 2D images of different slices through the scanned object were reconstructed using the filtered back projection technique. To determine attenuation coefficient, two sets of measurements were recorded; one taken for the sample and the other one for the reference material, chosen to be water.
3. Results and Discussion

Figure 2 shows an example of reconstructed attenuation image for one slice through one batch of gel, irradiated at 25 Gy. Ring artifacts associated with CT can be seen in the reconstructed images. The image reconstruction procedure was repeated for each batch of irradiated gel. From the reconstructed images, a consistent region of interest was selected, with average and standard deviation values calculated.

![Figure 2: (a) non-irradiate (left) and irradiated (right) PAGAT gel at 25 Gy; (b) reconstructed attenuation map; (c) reconstructed TOF map](image)

The variation of ultrasound attenuation as a function of dose is illustrated in Figure 3(a). Linear regression was used to determine the attenuation coefficient along with its related uncertainties in dose range of 0-30 Gy. The attenuation coefficient was calculated to be 1.44 ± 0.08 dB m-1Gy-1 and R² (adjusted coefficient determination) of 97% (P= 6.86E-6). Even though the overall attenuation coefficient measured at various doses for PAGAT is different to that previously reported for PAG (2.9 ± 0.3 dB m-1Gy-1) and MAGIC gel (4.2± 0.3 dB m-1Gy-1), the trend is similar to those previously reported by Mather et al for attenuation-dose sensitivity with the ultrasound fundamental frequency of approximately 4MHz [8-11].

![Figure 3: Ultrasound attenuation and TOF measured for PAGAT gel across a variety of doses- error bars are the standard deviation of the ROI](image)
Figure 3(b) illustrates the variation of the time of flight (TOF) as a function of absorbed dose. From TOF, inverse ultrasound speed was calculated. Linear regression was used and the dose sensitivity for inverse ultrasound speed values was determined to be $1.37 \times 10^{-4} \pm 0.10 \times 10^{-4} \text{ s m}^{-1} \text{ Gy}^{-1}$ ($R^2 = 95\%$; $P=5.31E-5$). This dependency of inverse acoustic speed on dose agrees with the results achieved by Mather et al for inverse acoustic speed of propagation as function of dose ($1.8 \times 10^{-4} \pm 1 \times 10^{-5} \text{ s m}^{-1} \text{ Gy}^{-1}$) [8-11, 22].

4. Conclusion

The capability of ultrasound CT was investigated through quantitative assessment of a PAGAT gel dosimeter via attenuation and TOF measurements exhibiting sensitivity to dose comparable to those previously reported [8-11].

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6. References

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