PAGAT gel dosimeters for dose distribution measurements in the vicinity of high-density implants: A preliminary study

A Asena¹, T Kairn¹,², S B Crowe¹, S T Smith¹ and J V Trapp¹
¹School of Chemistry, Physics and Mechanical Engineering, Queensland University of Technology, Brisbane, Australia
²Genesis CancerCare Queensland, Brisbane, Australia

E-mail: a.asena@qut.edu.au

Abstract. This work examined the suitability of the PAGAT gel dosimeter for use in dose distribution measurements around high-density implants. An assessment of the gels reactivity with various metals was performed and no corrosive effects were observed. An artefact reduction technique was also investigated in order to minimise scattering of the laser light in the optical CT scans. The potential for attenuation and backscatter measurements using this gel dosimeter were examined for a temporary tissue expander’s internal magnetic port.

1. Introduction
The success or failure of radiation therapy treatments is largely dependent on the ability to deliver the prescribed dose to the patient within a narrow tolerance. However, the human body consists of many components that vary in density which have been shown to cause complications in treatment planning and hence delivery [1, 2]. These can include naturally occurring internal inhomogeneities, as well as man-made biomaterials such as implants and prostheses. While these may be necessary for the survival or quality of life of radiotherapy patients, they also have the potential to seriously compromise the accuracy of radiotherapy treatment planning, and hence delivery. This work examines the feasibility of using the PAGAT gel dosimeter [3] for dose distribution measurements around high-density implants.

Gel dosimeters have the capacity to record radiation dose distributions in three-dimensions (3D) making them a very promising dosimetric tool for external beam radiotherapy [4-13]. It has been shown that the PAGAT gel formulation is approximately radiologically water equivalent for electron and photon beams [14] and is therefore an ideal 3D dosimeter for studying the effects of implants on patient dosimetry. The main advantage of using a gel dosimeter for this work is that complex shaped implants can be investigated due to their complete immersion in the gel thus alleviating the requirement of simplified geometry. Using PAGAT gel also means the conditions of the implant placement in the patient are matched. Here we present an examination of the suitability of using PAGAT gel dosimeters for dose distribution measurements in the vicinity of a temporary tissue expander’s internal magnetic port.
2. Methodology

2.1 System optimisation
Before the PAGAT gel dosimeter was used for dose distribution measurements around high-density implants, an assessment of the reactivity with various metals was performed. Objects composed of stainless steel, brass, and zinc were suspended in the mixture and observed over a period of 7 days to examine any potential corrosive effects. An artefact reduction technique was also investigated whereby metal objects suspended in the gel formulation were imaged in the optical CT scanner with, and without a coat of black paint to determine the extent of scattering of the laser light in the imaging system.

2.2 Manufacturing the PAGAT gel
As per the recipe recommended by Venning et al. [3] and Khoei et al. [15], the PAGAT polymer gel formulation by % mass consisted of 4.5% N,N'-methylenbis-acrylamide (bis), 4.5% acrylamide (AA), 5% gelatine, 7 mM tetrakis (hydroxymethyl) phosphonium chloride (THPC), 0.01 mM hydroquinone (HQ) and 86% HPLC (Water). When the preparation of the final polymer gel solution was completed, it was transferred into phantom along with the implant and allowed to set by storage in a refrigerator.

2.3 Gel Irradiation
The internal magnetic port (IMP) of a Mentor temporary tissue expander was extracted from the implant and suspended in a container of gel. The magnetic disk (1.5cm diameter, 0.5cm thickness) allows the position of the valve inside the patient’s body to be determined. However, this IMP is composed of a high-density neodymium magnet cased in titanium, which has the potential to compromise the accuracy of radiotherapy treatment planning, illustrating the need for 3D dose distribution measurements. The gel container was irradiated with a 5x5cm², 6MV photon beam from a Varian 21iX Clinac. The post-manufacturing time was selected to be 24 hours.

2.4 Imaging
The container was imaged in a MGS Research IQScan optical CT scanner specifically designed for readout of irradiated gel dosimeters. The imaging parameters included a field of view (FOV) of 220mm, 720 projections, a 360° rotation range, allowing a resolution of 0.5mm pixels. This pre- and post-scan data was reconstructed using filtered-back projection to create a 3D model of the dose distribution surrounding the high-density implant.

3. Results and Discussion
The results displayed in figure 1 demonstrate that the application of a non-reflective coating to the suspended metallic object has substantially reduced imaging artefacts in the optical CT scanner. Additionally, no corrosive effects were observed for the various metal objects that were submerged in the PAGAT gel formulation.

The radiation-induced polymerisation of the PAGAT gel formulation displayed in figure 2 shows a visible dose depletion downstream of the magnetic disk. However, the suspension angle of the internal magnetic port prevented the optical CT scanner from detecting the under-dosed region. This issue is resolved by simply implementing a horizontal, and therefore symmetrical, suspension method for the implant that allows the scanning laser to traverse this under-dosed volume.

Figure 3 shows a single reconstructed slice produced by the optical CT scanner with a resolution of 0.5mm. Also included is a normalised profile of the slice; thus employing internal calibration for optimal dose to gel [16]. This image slice illustrates that dose measurements in the proximity of the container wall are susceptible to edge artefacts and therefore should be avoided. Similarly, the cylindrical shape of the metallic implant makes it difficult to discern whether the profile peaks visible in figure 3 are the result of the production of secondary particles in the metal causing increased polymerisation, or more likely an increase in the laser light scatter.
**Figure 1.** Image slices of stainless steel bolt uncoated (left) and coated (right) with black paint submerged in PAGAT gel. These were obtained using the optical CT scanner at a resolution of 1mm.

**Figure 2.** An example treatment being delivered to the gel container is shown (left) alongside a photo of the PAGAT gel container with the suspended internal magnetic port post-irradiation (right).

**Figure 3.** Optical CT image slice of gel container with 0.5mm resolution with an indicator of profile location and beam direction (left) with corresponding profile plot (right).
Despite the absence of qualitative data regarding attenuation effects of the implant, this study demonstrated the viability of using the PAGAT gel dosimeter for attenuation and backscatter measurements of a temporary tissue expander’s internal magnetic port.

4. Conclusions
The suitability of the PAGAT gel dosimeter for use in dose distribution measurements around high-density implants was evaluated. This work demonstrated the potential that with an optimized gel dosimetry system, various implants can be placed into phantoms and followed through the clinical scenario of CT scanning, treatment planning, irradiation, and evaluation.

5. Acknowledgments
This work was partly funded by Australian Research Council Linkage Project LP110100401 in conjunction with the Wesley Research Institute.

6. References
[1] Kairn T et al 2013 Australas. Phys. Eng. Sci. Med. 36 209-17
[2] Kairn T et al 2013 J. Phys.: Conf. Ser. 444 012108
[3] Venning A J et al 2005 Phys. Med. Biol. 50 3875-88
[4] Trapp J V et al 2001 Phys. Med. Biol. 46 2939-51
[5] Trapp J V et al 2002 Phys. Med. Biol. 47 4247-58
[6] Lepage M et al 2002 Phys. Med. Biol. 47 1881-90
[7] Mather M L et al 2003 Ultrasonics 41 551-9
[8] Trapp J V et al 2004 Phys. Med. Biol. 49 N139-46
[9] Venning A J et al 2004 J. Phys.: Conf. Ser. 3 155-8
[10] Baldock C 2006 J. Phys.: Conf. Ser. 56 14-22
[11] Bosi S et al 2009 Phys. Med. Biol. 54 275-83
[12] Gorjiara T et al 2011 Med. Phys. 38 2265-74
[13] Baldock C et al 2010 Phys. Med. Biol. 55 R1-63
[14] Brown S et al 2008 Appl. Radiat. Isot. 66 1970-4
[15] Khoei S et al J. Phys.: Conf. Ser. 250 012019
[16] Taylor M L et al 2007 Phys. Med. Biol. 52 3991-4005