

Assessment of the effects of CT dose in averaged x-ray CT images of a dose-sensitive polymer gel

This content has been downloaded from IOPscience. Please scroll down to see the full text.

2015 J. Phys.: Conf. Ser. 573 012075

(<http://iopscience.iop.org/1742-6596/573/1/012075>)

View [the table of contents for this issue](#), or go to the [journal homepage](#) for more

Download details:

IP Address: 131.181.251.22

This content was downloaded on 13/01/2015 at 01:57

Please note that [terms and conditions apply](#).

Assessment of the effects of CT dose in averaged x-ray CT images of a dose-sensitive polymer gel

T Kairn^{1,2}, M B Kakakhel³, H Johnston⁴, A Jirasek⁴ and J V Trapp²

¹Genesis Cancer Care Queensland, Brisbane, Australia

²Science and Engineering Faculty, Queensland University of Technology, Brisbane, Australia

³DPAM, Pakistan Institute of Engineering and Applied Sciences, PO Nilore, Islamabad 45650, Pakistan

⁴Department of Physics and Astronomy, University of Victoria, Victoria BC, Canada

E-mail: t.kairn@gmail.com

Abstract. The signal-to-noise ratio achievable in x-ray computed tomography (CT) images of polymer gels can be increased by averaging over multiple scans of each sample. However, repeated scanning delivers a small additional dose to the gel which may compromise the accuracy of the dose measurement. In this study, a NIPAM-based polymer gel was irradiated and then CT scanned 25 times, with the resulting data used to derive an averaged image and a “zero-scan” image of the gel. Comparison between these two results and the first scan of the gel showed that the averaged and zero-scan images provided better contrast, higher contrast-to-noise and higher signal-to-noise than the initial scan. The pixel values (Hounsfield units, HU) in the averaged image were not noticeably elevated, compared to the zero-scan result and the gradients used in the linear extrapolation of the zero-scan images were small and symmetrically distributed around zero. These results indicate that the averaged image was not artificially lightened by the small, additional dose delivered during CT scanning. This work demonstrates the broader usefulness of the zero-scan method as a means to verify the dosimetric accuracy of gel images derived from averaged x-ray CT data.

1. Introduction

Given the obvious value of 3D gel dosimetry as a technique for verifying the accuracy and deliverability of radiotherapy treatment plans [1-3], the reading out of gel measurements using an imaging modality already available in many radiotherapy departments is highly desirable [4]. For this reason there is increasing interest in the use of x-ray computed tomography (CT) [5] to provide images of dosimetry gels [6-8].

While the small radiation-induced density changes in polymer gel dosimeters can be detected using clinical x-ray CT scanners, the low signal-to-noise ratio (SNR) in the resulting images means that the results are not immediately useful without further processing [7]. The main method for enhancing the SNR in an x-ray CT image of a dosimetry gel is to scan the gel multiple times and calculate the mean of each pixel value across the various scans, to give an averaged image [6, 7]. Obviously, each time the gel is CT scanned, it receives a small additional radiation dose which may affect the result of the measurement. For example, when a PAGAT gel [9] is exposed to 6 MV x-ray doses of up to 6.9 Gy and then CT scanned 50 times using a 120 kVp x-ray source, the resulting image pixel values can be



shown to increase from one scan to the next, resulting in an averaged image that provides dose measurements 5% higher than the doses measured in the first CT image alone [10].

The inaccuracy caused by the gel's response to the CT dose can be mitigated by: optimising the gel for CT readout [11]; optimising CT scanning parameters to produce maximised signal-to-noise images with minimised dose [7, 12]; and by directly removing the effects of the CT dose by subtracting "background" CT scans of non-irradiated (but CT imaged) gel samples from the scans of the irradiated gel samples. When examining the results of applying such techniques, a dosimetrically reliable reference image is needed, against which the averaged image can be evaluated. We propose that Kakakhel *et al*'s zero-scan method [10, 13, 14] (described below) is well suited to this purpose.

2. Method

2.1 Gel fabrication and irradiation

Two identical containers of polymer gel were produced according to a recipe optimised for x-ray CT by Jirasek *et al* [11, 15]. The gel consisted of 15% NIPAM (TCI America, Portland, OR), 4.5% BIS (Sigma-Aldrich Canada, Oakville, ON), 5% gelatin (Sigma-Aldrich), 75.5% deionized water and 5 mM tetrakis-hydroxymethyl-phosphonium-chloride (THPC) (Sigma-Aldrich) as antioxidant [11].

One container of gel was left un-irradiated, to provide a background measurement, and the other was irradiated using three intersecting $3 \times 3 \text{ cm}^2$ fields from a Varian Clinac 21EX linear accelerator (Varian Medical System, Palo Alto, USA), which delivered up to 27.6 Gy to the centre of the gel. (This treatment plan is illustrated in [15].)

2.2 X-ray CT image acquisition

X-ray CT images were acquired using a GE HiSpeed FX/i single-slice CT scanner (GE Medical Systems, Milwaukee, USA) with a 120 kVp source operating at 200 mAs. One 3 mm slice was scanned 25 times, in each container of gel, and reconstructed using a standard convolution kernel over a 25 cm field of view. Each image acquisition took approximately 2 seconds; scanning each sample took 50 seconds. No x-ray tube cooling breaks were required. The background gel was scanned three minutes after the irradiated gel.

2.3 X-ray CT image analysis

Prior to analysis, a background image from the un-irradiated gel was subtracted from each of the 25 images of the irradiated gel, to remove scanning artefacts [16, 17]. The values of each individual pixel value (Hounsfield unit, HU) in the resulting images were then averaged over the 25 scans to produce an averaged image [6, 7], and linearly extrapolated back to a theoretical "zero-scan" image of the gel without the effects of the small additional dose delivered during CT scanning [10, 13, 14].

The contrast (C), contrast-to-noise ratio (CNR) and SNR of the resulting images were then evaluated as [18]:

$$C = \frac{P_{high} - P_{low}}{P_{low}}, \quad CNR = \frac{P_{high} - P_{low}}{\sigma_{low}} \quad \text{and} \quad SNR = \frac{P_{high}}{\sigma_{high}} \quad \text{or} \quad \frac{P_{high}}{\sigma_{high}}$$

where P_{high} and P_{low} were the mean values in 1 cm diameter regions of interest in, respectively, high and low dose areas of each image and σ_{high} and σ_{low} were the standard deviations from those means.

3. Results

Qualitative examination of the images shown in figures 1(a)-(c) suggests that the averaged and zero-scan images are affected by less noise than the image from the first scan, with the averaged image being the least noisy of the three images. This observation is supported by the data shown in table 1.

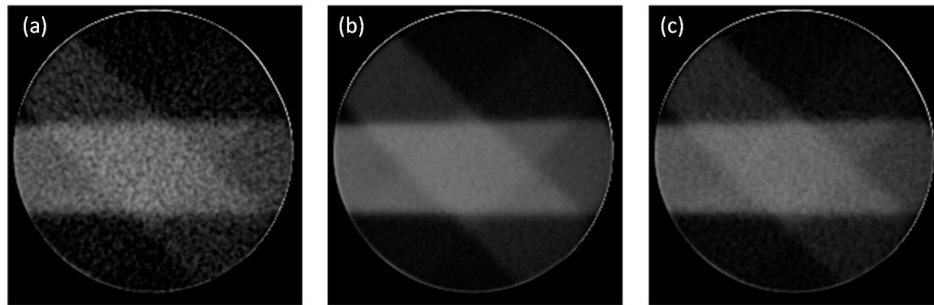


Figure 1. Transverse images of irradiated gel, derived from (a) the first of 25 sequential CT scans of the gel, (b) the average pixel values (HU) from all 25 scans of the gel and (c) the result of projecting the pixel values from the 25 scans back to the “zero scan” of the gel.

Table 1. Contrast, CNR and SNR, determined from images shown in figure 1.

Image	Contrast	CNR	High-dose SNR	Low-dose SNR
First scan	20.1	15.1	8.3	0.8
Average	21.2	67.9	33.4	3.2
Zero scan	21.8	33.9	21.4	1.6

The profiles in figures 2(a) and (b) show the same reduction in noise in the results achieved with the averaging and zero-scan analysis methods, while also demonstrating that the pixel values in the averaged image are not noticeably elevated, compared to the zero-scan result. This result suggests the averaged image has not been artificially lightened by the small, additional dose delivered during CT scanning.

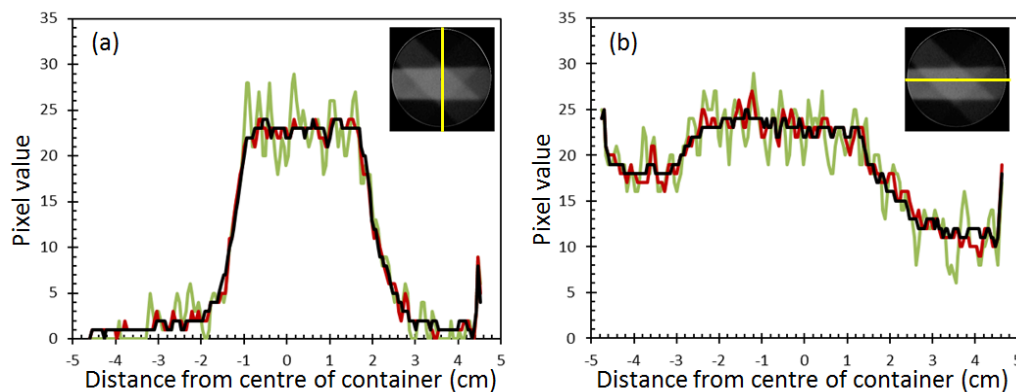


Figure 2. Profiles through the dose images of the irradiated gel, shown in figure 1, where the green (light grey) line represents data from the first scan, the black line represents data from the average of the scans and the red (dark grey) line represents data from the zero scan. Insets show positions of profiles.

Figure 3 shows a histogram of the gradients of the linear fits used to extrapolate the zero-scan pixel values, for all pixels in the transverse image of the gel, and indicates that all gradients are small (no value falls outside the range $-0.30 < \text{gradient} < +0.30$) and that values are symmetrically distributed around zero; pixels are neither becoming systematically lighter (as they would if the result was affected by radiation dose from the CT) nor systematically darker (as they would if the CT dose was being over-corrected), between one CT scan and the next.

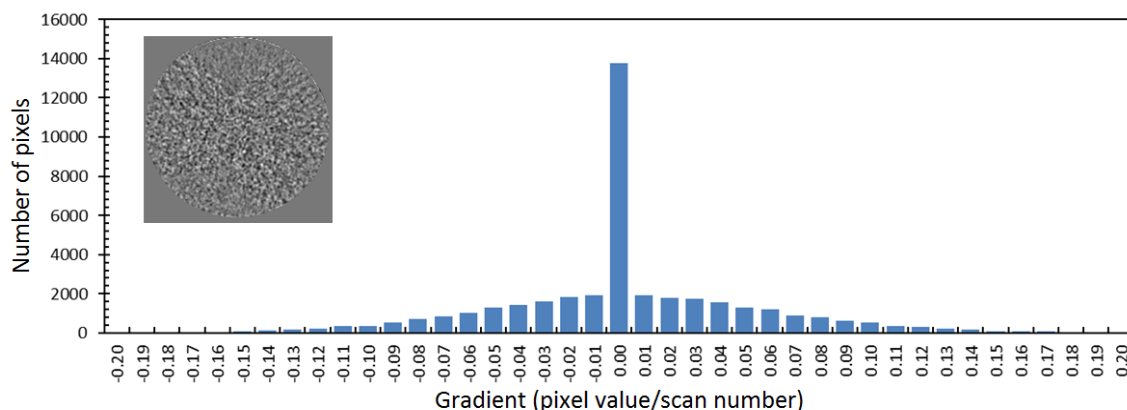


Figure 3. Histogram of gradients obtained from zero-scan extrapolation. Inset shows map of gradient values, with 0.0 appearing as mid-grey, values greater than 0.0 appearing as lighter grey (to white) and values less than 0.0 appearing as darker grey (to black).

4. Conclusion

This work used the zero-scan method to show that an averaged series of CT images of an irradiated gel were not affected by the dose delivered during the x-ray CT imaging process, and thereby demonstrated the broader usefulness of the zero-scan method as a means to verify the dosimetric accuracy of gel images derived from averaged x-ray CT data. A zero-scan image of a CT-scanned gel sample should be acquired and analysed each time the gel recipe or scanning protocol is altered, as well as whenever the averaging of CT scans of a dosimetric gel is being attempted for the first time.

5. Acknowledgements

TK's contribution to this study was supported by Premion (Genesis Cancer Care Queensland), in association with the Wesley Research Institute and the Queensland University of Technology, as part of Australian Research Council linkage project LP110100401. The authors wish to thank the Vancouver Island Cancer Centre for kindly providing access to their x-ray CT scanner.

6. References

- [1] Baldock C *et al* 2010 *Phys. Med. Biol.* **55** R1-63
- [2] Korreman S S 2013 *J. Phys.: Conf. Ser.* **444** 012007
- [3] Kairn T *et al* 2012 *Phys. Med. Biol.* **57** 3359-69
- [4] Baldock C 2006 *J. Phys.: Conf. Ser.* **56** 14-22
- [5] Brown S *et al* 2008 *Appl. Radiat. Isotopes* **66** 1206-12
- [6] Hilts M *et al* 2000 *Phys. Med. Biol.* **45** 2559-71
- [7] Jirasek A 2013 *J. Phys.: Conf. Ser.* **444** 012005
- [8] Hill B *et al* 2005 *Brit. J. Radol.* **78** 623-30
- [9] Venning A J *et al* 2004 *J. Phys.: Conf. Ser.* **3** 155-8
- [10] Kakakhel M B *et al* 2011 *Med. Phys.* **38** 5130-35
- [11] Jirasek A *et al* 2012 *Phys. Med. Biol.* **57** 3137-53
- [12] Hilts M *et al* 2005 *Phys. Med. Biol.* **50** 1727-45
- [13] Kakakhel M B *et al* 2013 *J. Phys.: Conf. Ser.* **444** 012091
- [14] Kakakhel M B *et al* 2014 *J. Appl. Clin. Med. Phys.* (In press)
- [15] Johnston H *et al* 2012 *Phys. Med. Biol.* **57** 3155-75
- [16] Trapp J V *et al* 2001 *Phys. Med. Biol.* **46** 2939-51
- [17] Trapp J V *et al* 2004 *Phys. Med. Biol.* **49** N139-46
- [18] Kairn T *et al* 2010 *Phys. Med. Biol.* **55** N533-45