Normoxic Gel dosimetry using multislice X-ray CT: Preliminary study

N. Gopishankar, S. Vivekanandhan, S. Thulkar, R.K Bisht, V. Subramani, M.A. Laviraj, K. JothyBasu, S. SenthilKumaran, S.S. Kale, G.K Rath, B.S Sharma

All India Institute of Medical Sciences, New Delhi, India

Email: gshankar1974@yahoo.com

1. Introduction

In recent years there has been significant increase in the utility of X-ray CT for gel dosimetry due to easy accessibility of CT in clinical radiation therapy. Among various gel dosimeters available, Normoxic polymer gels, is a new class of dosimeter that can be manufactured on a bench-top in presence of oxygen. Several antioxidants are available of which THPC was found to be very effective in oxygen scavenging capabilities. Several authors have shown that X-ray CT imaging is capable of providing dose resolutions approaching those of MRI gel within shorter imaging time (Hilts et al 2005). The dose information extracted from polymer gels are by radiation induced density change, which provides contrast in CT images. The focus of this paper is to outline considerations for implementing CT polymer gel dosimetry, specifically phantom design, CT imaging protocol, image averaging, and gel dose response. Image processing may be considered to be composed of two independent stages: acquisition stage/detection stage and processing/display stage. The most commonly used ‘hands-on’ form of digital image processing in medical imaging is ‘image enhancement’. In this work, PAGAT Normoxic gel was investigated with a multislice X-ray CT. We establish the dose response reproducibility of PAGAT dosimeter when imaged with X-Ray CT for a range of irradiation times post gel manufacture (23h). Various factors influencing image noise for CT based gel dosimetry was studied and ways to improve were outlined. We also investigated the implementation of digital image filtering techniques on gel CT images to reduce image noise and improve dose resolution using several spatial filters.

2. Materials and methods

Siemens Volume Zoom CT scanner was used for all CT imaging. PET (Polyethylene Terephthalate) containers were used and not glass containers as the latter can produce extreme artefacts. Scan parameters (as show in Table 1) were varied from set of parameters to access dependence of noise on each parameter. From each set of scan parameters, two images were taken to remove artefacts by background subtraction for noise study. Standard deviation in CT number (σNCT) was measured from pixel region at centre of final images. FOV (130x130mm) was used for dose response experiments. For 512x512 matrix size in CT images, scanned pixel dimension was 0.25mm. For
image averaging study FOV of (380x380mm) was used. Image processing and analysis were done using Matlab software.

| Scan parameter                  | Values                  |
|---------------------------------|-------------------------|
| Tube voltage (kV)               | 80, 120, 140            |
| Tube current (mA)               | 80, 125, 250, 300, 350, 400 |
| Slice Scan time (s)             | 1                       |
| Reconstruction Algorithm        | B10, B30, B41, B60, B80 |
| Slice thickness (mm)            | 0.5, 1, 2.5, 5, 8       |
| Field of View (mm)              | 50, 130, 250, 380, 400, 478 |

**Table 1**

**A. Factors influencing image noise**

**A1. kV & mAs study**

Increasing x-ray tube voltage (kV), x-ray tube current (mA) decreases image noise as shown in figure 1 and 2.

Also previously it has proven that increasing tube voltage has a greater effect on image noise than does an equal change in tube current (Hilts et al. 2005).

**A2. Effect of Phantom Diameter**

The effect of phantom diameter on image noise was investigated by imaging water filled PET containers with different diameters. CT image noise increases with phantom size. Similar work was done with glass container previously (Hilts et al. 2005). Irrespective of phantom material used, CT image noise tends to increase with phantom size.
A3. Image averaging
The ability of a gel dosimetry read-out technique to produce spatially uniform images is crucial for accurate gel dosimetry (Hilts et al 2005). Mean and standard deviation for 36 spatially distinct 21x21 pixel ROI’s in a single image, 16 image averages and 32 image averages are shown in figure 4, 5 and 6 respectively.

![Fig 4](image1)
![Fig 5](image2)
![Fig 6](image3)

A4. Reconstruction Algorithm
The reconstruction algorithm has a significant influence on the image noise. The algorithm (B30 by Siemens) appears suitable for most gel dosimetry applications. The effect of different algorithms available on Siemens scanner on image noise is shown in figure 7.

![Fig 7](image4)

A5. Slice thickness and FOV (Spatial resolution)
Increasing slice thickness and FOV decreases image noise. A comparative study was done for different tube voltage and tube current combination for different slice thickness. The standard deviation was found to be minimal for combination of 140kV/140mA.

![Fig 8](image5)
![Fig 9](image6)
B. Gel Preparation

Normoxic gel was prepared under normal atmospheric conditions. The components used for the preparation of the dosimeter were 6% gelatin (300 Bloom from Porcine skin), 3% Acrylamide, 3% N, N’ methylene-bis-acrylamide (BIS), 88% distilled water and 10mM tetrakis(hydroxy methyl) phosphonium chloride (THP). All the components were purchased from Sigma Aldrich, India. For preparation of PAGAT gel, 6% of gelatin by total weight of the dosimeter was mixed with 88% distilled water and allowed to soak for 45 minutes before heating to 50°C in specially designed water bath with temperature control (thermostat), also cross checked with a thermometer. Waterbath was designed in-house specifically to prepare 10 to 15 Liters of gel. The container with gelatin was heated to 50°C and simultaneously stirred with overhead stirrer. BIS (3%) was added and stirred thoroughly in the gel solution till it dissolved completely for 30 minutes. 3% Acrylamide was added subsequently and the whole content was stirred for an hour. Once a clear solution was obtained 10mM of THPC was added and stirred and the container was removed from waterbath. A final volume of 4.5 l of gel was prepared. The gel was immediately poured into the three PET containers (each with 1mm thickness and 1500mL capacity) till screw top and tightly sealed with clingfilm and container lid. One container was used for calibration, one for clinical beam exposure and one for background subtraction purpose. The gel containers were immediately covered with black plastic cover to avoid exposure to daylight that might cause photopolymerization and then were refrigerated at 5°C.

C. Gel Irradiation

Irradiations were done approximately 23h post manufacture on Varian Clinac2300CD linear accelerator (Varian Assoc., Palo Alto, CA). The containers were brought to the room temperature of linac room before exposure to radiation. The PET containers (10cm dia, 18.5cm height) for exposure were left in the linac room for 1 hr. The PET (1) was irradiated to doses from 0Gy to 14Gy at Dmax by large flask geometry method (Taylor et al. 2007). The PET (2) was irradiated with four intersecting 4 x 4cm² 6MV field doses of 2, 5, 7, and 11Gy at the depth of maximum dose. The PET (3) container was used for background subtraction. Reference marks were made on the containers for scanning reproducibility. After irradiation the gel containers were exposed to atmosphere one day after irradiation in order to make gels inactive and thus prevent further polymerization.

D. Gel imaging

CT imaging of irradiated gel was performed using Siemens Volume Zoom CT scanner. Irradiated and unirradiated gel used for background subtraction were positioned and oriented identically within scanner bore using reference marking. Acquisition parameters for dose response experiments were chosen from overall scanner parameters in table 1 and as follows: tube voltage 140kV, tube current 200mA, scan time 1sec, FOV 130x130, image thickness 2.5mm, Reconstruction algorithm B30 medium. Chosen FOV well encompassed cylindrical phantom. Images were obtained at 21 ± 1 °C. Before scanning gel containers were left in CT room for an hour to attain the scanning room temperature. Number of images averaged for dose response study was 15 images per scan position to reduce heat loading and imaging time without much loss in SNR. Artefacts were removed by subtracting an identical but unirradiated average background gel image from irradiated gel image.
E. ΔN_CT – dose response
ΔN_CT – dose responses showed a linear region for doses up to 12 Gy followed by slight decrease in response. The dose sensitivity of (4.68 ± 0.3) × 10⁻³ HcGy⁻¹ was obtained 24 hrs post irradiation. The mechanism for increase of ΔN_CT with dose must be related to increase in linear attenuation coefficient of the gel relative to that of water (Hilts et al. 2004). Overall the monoexponential fit was found to be better than the linear fit.

F. Reproducibility
The ΔN_CT – dose response reproducibility for given gel was determined over several imaging sessions on different days. The average slope for post irradiation hrs 24, 53, 145, 288, 436 was found to be (4.96 ± 0.3) × 10⁻³ HcGy⁻¹ for linear fit (0 to 12 Gy). Jirasek et al 2006 as shown that time of PAGAT gel CT scanning post gel irradiation does not alter resultant gel dose response characteristics. However we observed a slightly deviation in slope, intercept values. This may be due to reason that imaging requires proper temperature control system for improving the temporal stability (De Deene et al 2007).

G. Influence of gel temperature during imaging
The effect of gel temperature during imaging on ΔN_CT – dose response was investigated a) immediately after removing from refrigerator b) after attaining room temperature on same day. The response remained linear for both conditions. The sensitivities of the ΔN_CT – dose response however differed and are given by:
ΔN_CT(H) = (6.85 ± 1.1) × 10⁻³ dose (cGy), condition 1 = immediate scanning
ΔN_CT(H) = (5.12 ± 0.2) × 10⁻³ dose (cGy), condition 2 = scanning at room temperature

L. Digital filtering
Digital image filtering is an effective method in reducing image noise while maintaining accurate spatial dose information. Generally it is performed in either frequency domain or spatial domain. The evaluated filters in this study are: mean (amean, harmean, charmean, gmean), median, midpoint, wiener2, alpha-trimmedmean, adaptivemedian. For this study slope of linear region (0 to 12 Gy) from calibration gel was used to calculate σ_D. Measured noise σ_N_CT(H) from region of interest in the gel (25pixels) exposed with clinical beams and calculated values of σ_D and dose resolution (ΔΔ₉₅%) were analyzed for dose regions in gel irradiated for simulated clinical treatment. The response had dose region of slope 216±14 cGy/H (R² = 0.9972) and ΔΔ₉₅% of 498 cGy.

3. Results and Discussion
The Siemens VolumeZoom x-ray CT scanner was optimized to evaluate PAGAT Normoxic gel dosimeters. In the image averaging study the number of images required to reduce noise was found to be 32. Further increase in number of images would certainly reduce noise but at the cost of tube
loading and imaging time. In the phantom size study phantoms with smaller dimensions were effective in reducing $\sigma_{N_{CT}}(H)$. The noise decreases with increase in kV, mAs, slice thickness, and field of view. But scan parameters for dose response study were chosen similar to a previous study in order to get comparative results. The average slope was found to be $(4.96 \pm 0.3) \times 10^{-3}$ HcGy$^{-1}$ for the linear region. But full response (0 to 14Gy) is well modeled by a monoexponential fit than a linear fit. The large flask method used for gel calibration is straightforward and less prone to setup errors and is commendable for X-Ray CT gel dosimetry. In the stability study dose response was linear but with slight upward shift in the response curve. Proper temperature controlling devices are required to control the gel temperature to produce good results. The dose resolution in PAGAT CT images can be improved by filtering with spatial filters for reducing noise (Hilts et al 2004). Meanfilter and wiener2filter gave similar filtering results. In our study dose resolution highly improved by applying alpha-trimmed filter with 7x7pixel mask which showed a DA$^{95}$% of 233cGy. In case of midpoint filter the $\sigma_{N_{CT}}$ values increased with increase in mask size.

4. Conclusion
In summary gel dosimetry with multislice CT scanners significantly improves the quality of imaging and specifically reduces the imaging time. Also in general density changes occurring in irradiated polymer gel due to X-ray CT imaging are minute and therefore image contrast is very low. Hence choosing optimal scanning parameters and post-image acquisition data processing like image filtering is vital for CT gel dosimetry. Future study will include the study of other filters such as SUSAN and TPMEM for noise reduction in CT gel dosimetry.

References
[1] Trapp J V et al, Phys. Med. Bio, 46, 2939-2951 (2001).
[2] Hilts M et al, Med. Phys, 31, 39-49 (2004).
[3] Hilts M et al, Med. Phys, 50, 1727-1745 (2005).
[4] Jirasek A et al, Phys. Med. Bio, 51, 2599-2617 (2006).
[5] Taylor M L et al, Phys. Med. Bio, 52, 3991-4005 (2007).
[6] De Deene et al, Phys. Med. Bio, 52, 2719-2728 (2007).