Internal Calibration of gel dosimeters: A feasibility study

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Abstract. In this work we test the feasibility of a new calibration method for gel dosimetry. We examine, through Monte Carlo modelling, whether the inclusion of an organic plastic scintillator system at key points within the gel phantom would perturb the dose map. Such a system would remove the requirement for a separate calibration gel, removing many sources of uncertainty.

1. Introduction
For gel dosimeters to be clinically useful the acquired dose information must be reliable, accurate and precise. There are several sources of uncertainty in absorbed dose measurements taken with gel dosimeters, broadly summarized as chemical, radiation, scanning [1], and mathematical contributions [2]. Much of the uncertainty arises during the calibration process, and there is often a tradeoff between benefits and drawbacks with different calibration methods.

To use a gel dosimeter one would normally produce a large enough volume so that a ‘phantom gel’ and ‘calibration gel’ are taken from the same manufacturing batch, therefore ensuring initial chemical consistency. The calibration gel is irradiated to a range of doses such that a sufficient number of data points are available to determine a calibration function of ‘signal vs dose’ (the signal being R2, optical attenuation, density etc, depending on imaging modality, and noting that the calibration gel is imaged under the same conditions as the phantom gel). The calibration function is then used to convert images of the phantom gel to dose.

Several methods of handling the calibration gel have been presented in the literature. These methods include dividing the calibration gel into several small vials which are irradiated to varying doses [3], irradiating a single large flask of calibration gel with several small beams [4, 5] or with electron depth-dose information [6] and irradiation along the axis of gel-filled test tubes using linac depth-dose data in water [7].

Some calibration methods eliminate the need for a calibration gel by obtaining data points directly from the phantom gel, therefore eliminating some setup and positional uncertainties. These methods include comparison of selected regions of interest in the phantom gel with planning system predictions [8] and equalization of dose-area histogram data from an image slice of the gel to that of a film placed at an equivalent depth [9].
There is significant potential for introducing errors into the irradiation process when separately irradiating the phantom gel and the calibration gel. Taylor et al. [10, 11] examined several variations of the above methods and found that errors in the dose to the calibration phantom tend to be within 1% for the ‘small vials’ and ‘large flask’ method, and about 2% for the ‘test tube’ method. In addition to uncertainties in the delivered dose, because the calibration gel is separate to the phantom gel additional errors may be introduced due to different temperature histories, irradiation conditions and imaging conditions [1]. For the methods which do not utilize a separate calibration gel, there is the possibility of errors due to region-of-interest selection, planning system inaccuracies, scattered radiation contributions and image slice selection.

The ideal solution to reduce calibration uncertainty would be to place reference dosimeters within the phantom gel at key locations to obtain the calibration points. The reading obtained from the dosimeter could then be accurately applied to the post-irradiation images, thus eliminating the sources of error described above. Unfortunately, placing dosimeters such as ionization chambers and thermoluminescent dosimeters inside the phantom gel would perturb the radiation field, thus altering the very dose information that was intended to be measured. One alternative would be to utilize a gel equivalent dosimeter for this task, and as such, organic plastic scintillators with a density of 1.032 g/cm$^3$ could prove suitable. In this work we present a Monte Carlo feasibility study for the use of organic plastic scintillators to provide calibration data points from directly within the phantom gel.

2. Methods and Materials
Monte Carlo simulations were performed using the EGSnrc/BEAMnrc software [12]. The setup simulated was a 20 $\times$ 20 $\times$ 20 cm volume of polyacrylamide gel (PAG) [13] embedded with scintillators of volume 2 $\times$ 2 $\times$ 0.25 cm. A pre-commissioned model [14] of an Elekta Precise linac was used with a source to surface distance of 90 cm and field size of 10 $\times$ 10 cm. Voxel size was 0.25 $\times$ 0.25 $\times$ 0.25 cm. The nominal photon energy was 6 MeV.

Figure 1 shows the geometry of the scintillator/gel setup. Three scintillators were positioned on the beam central axis at depths of 1.5 cm, 10 cm, and 18.5 cm. In practical use, organic plastic scintillators are coated with a reflective paint and opaque plastic tape [15] and so the simulations were repeated to include scintillator only, and scintillator with reflecting paint and light blocking tape. The atomic compositions of the various materials are given in Table 1 [10]. For the simulations where paint and tape were used the materials were approximated to be proportionally ‘mixed’ together with the gel in the voxels immediately surrounding the scintillators having a paint layer of 100 $\mu$m thickness and tape layer of 500 $\mu$m thickness. Additionally, two simulations of a ‘gel only’ phantom were obtained with different random number seeds for comparison of results.

Figure 1 – Layout of phantom geometry
Table 1 - Different simulations performed

| Setup | Simulation                                                                 | Chi-square (compared to Simulation 1) |
|-------|---------------------------------------------------------------------------|---------------------------------------|
| 1     | PAG only                                                                  |                                       |
| 2     | PAG with three scintillators on central axis as shown in Figure 1          | 0.000070                              |
| 3     | Same as Setup 2, however voxels surrounding the scintillator have paint and tape contributions | 0.000069                              |

Table 2 - Composition of Materials

| Material                          | Density (g/cm$^3$) | Atomic Composition – Fraction by Weight |
|-----------------------------------|-------------------|----------------------------------------|
| PAG                               | 1.02              | 0.107 H, 0.047 C, 0.017 N, 0.829 O, 0.915 Ti |
| Scintillator                      | 1.032             | 0.085 H, 0.915 C                         |
| Paint, tape and gel combination  | 1.008             | 0.112 H, 0.227 C, 0.021 N, 0.634 O, 0.006 Ti |

3. Results

Figure 2 shows the central axis depth dose information for the various simulations. The depth dose is normalized to the dose in a ‘PAG only’ phantom at 10 cm depth. Included in Table 1 is a chi-square comparison between each simulation and the ‘PAG only’ phantom. From the figure and the chi-square results, it can be seen that the inclusion of an organic plastic scintillator (with or without the paint and tape) in the gel has little overall perturbation of the dose in the gel. This is also confirmed by Bland and Altman testing [16] (not shown).

Figure 2 – depth dose data for the systems examined

![Figure 2](image)

Figure 3 shows the data from Figure 2 in the region close to $d_{\text{max}}$. Figure 4 is a plot of the percentage difference in dose with depth between the ‘PAG only’ simulation and the simulation with gel, paint and tape. From the figures it can be clearly seen that there is a decrease in dose of approximately 3.52 % at the location of the scintillators as compared to the ‘PAG only’ simulation, followed by a slight increase dose of approximately 1% in the gel for approximately 1 cm downstream of the scintillator. The decrease in dose at the scintillator can be overcome through careful calibration of each scintillator for dose-in-water. The increased dose in the 1 cm following the location of the scintillator is thought to be due to increased electron scatter from the scintillator; however this requires further investigation. Nevertheless, the initial solution would be to ensure that the 1 cm depth of gel
immediately following the scintillator is not be used in analysis of dose maps, and that scintillators not be placed within 1 cm of key regions of the phantom gel.

Figure 3 – Depth dose information close to $d_{\text{max}}$

![Figure 3](image3.png)

Figure 4 – Percentage difference in depth dose between Simulations 1 and 3

![Figure 4](image4.png)

4. Discussion
This work has shown that, in principle, the direct measurement of dose within the phantom gel can be achieved through the use of well calibrated organic plastic scintillators. This work is ongoing however initial results indicate that the scintillators should be located such that they are further than 1 cm ‘upstream’ from any key locations within the phantom gel.

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