Effect of container size on the accuracy of polymer gel dosimetry

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1. Introduction
The radiation-induced polymerization reaction in polymer gel dosimeters is exothermic. The rate of polymerization for vinyl groups depends on the temperature. Thus, the amount of polymer formed in a polymer gel dosimeter is not simply related to the incident radiation dose. It was clearly showed that the environment of the gel sample (air, water or Styrofoam) was shown to lead to a difference in the temperature rise within the gel during irradiation [1]. These authors had envisaged that a possible consequence of this phenomenon would be to modulate the quantity of polymer formed.

Herein, we show that the size of the container filled with gel being irradiated affects the values of $T_2$ determined by magnetic resonance imaging (MRI), and consequently leads to modulations in the determination of the absorbed dose.

2. Materials and Methods
Dosimeter gel was prepared in a 500 ml beaker under a vented hood using the following products (measured at room temperature): 344 g H$_2$O, 20 g gelatin from porcine skin (Type A), 18 g N,N'-Methylene-bisacrylamide, 18 g Acrylamide, and 0.664 g (10 mM) Tetrakis(hydroxymethyl) phosphonium chloride (THPC), all from Aldrich. The content of the beaker was continuously stirred. Gelatin was poured in water at room temperature and let to soak for 10 minutes. The solution was then heated to 45°C. One at a time, in this order, the bisacrylamide and acrylamide were added. When complete dissolution was observed, the mixture was cooled to 30 °C by placing the beaker in an ice bath. The THPC was pipetted into the solution in two identically sized measures of 0.332 g. At this point it is imperative that the gel be exposed to a minimal amount of oxygen. Thus, the mixture was immediately poured into eleven 2 ml plastic vials (wall thickness ~ 0.95 mm, i.d. 8.5 mm, section 0.57 cm$^2$) and five home-made rectangular containers (described below). The containers were immediately sealed with Parafilm and tape. Due to their photosensitivity, all samples were wrapped in aluminum foil. The samples were placed in a refrigerator at 4°C for 1 hour. The samples were removed from the refrigerator and submerged in H$_2$O at 25°C for 110 minutes before irradiation.

We constructed rectangular containers made from 4.2 mm thick Plexiglas plates bonded using C$_2$H$_2$Cl$_2$. The containers have a length of 17.9 ± 0.5 cm and square cross-sections of 0.81, 1.21, 2.89, 4.84 and 9.00 cm$^2$, respectively. Thus, these containers have an identical barrier to heat propagation and they only differ by their sections. This design should help isolate the temperature effects we are seeking to observe.

The samples were irradiated in a Plexiglas tank (~21 cm x 21 cm x 41 cm) filled with room temperature water. A thin Plexiglas sheet (4 mm) perforated at a 1.5 cm interval was designed to slide...
in the tank to hold the calibration vials tightly in place during irradiation. The same Plexiglas insert was used to immobilize the rectangular containers at the bottom of the tank during irradiation.

Six MV photons from a linear accelerator were used to irradiate the samples. The field size was 25 cm x 25 cm. The calibration vials were irradiated in two batches; five were irradiated at a maximum of 15 Gy and five at maximum of 4 Gy. The dose received by each vial was calculated using a calibrated depth-dose curve for 6 MV photons in water. One vial was left unirradiated.

We used a birdcage head coil in a Siemens Sonata scanner (1.5 T). The parameters of the multislice multi-echo sequence were: FOV 180 mm x 180 mm, 24 echoes, echo spacing of 40 ms, TR 6780 ms, matrix 256 x 256, 12 averages. The images were acquired in the sagittal plane. Seven 4 mm slices were obtained.

Data analysis was performed using modified in-house Matlab code [2] and Origin. $T_2$ maps were obtained by fitting pixel by pixel the last 22 echoes to a monoexponential function. The $T_2$ map was converted to a dose map using a monoexponential fit calibration curve ($T_2$ vs dose) obtained from the calibration vials. The analysis was performed on the central MR image where all the samples were seen. The depth-dose profiles in Fig. 1 are the average of the profiles for each rectangular container, which explains why the profile from the smallest container appears the noisiest.

3. Results and Discussion
The calibration curve is obtained from small calibration vials. That calibration is applied to the larger rectangular containers. The results indicate that the apparent dose decreases as a function of increasing container section (Fig. 1). This is linked to a larger value of $T_2$ and thus to a lower amount of polymer. It could be argued that the smaller container could suffer more from a possible oxygen contamination arising from oxygen trapped in the Plexiglas walls. However, this would lead to the opposite trend. Our interpretation is that the Plexiglass walls act as a barrier to the heat generated by the exothermic radiation-induced polymerization reaction. The heat is thus confined within the container, although it can propagate from warmer to cooler locations along the axis of the container. As the container section increases, this heat propagation appears to be less restricted, leading to a somewhat lower temperature in areas of maximal dose.

![Figure 1.](image)

**Figure 1.** Depth-dose curve for rectangular containers each with a different section. The apparent absorbed dose decreases as the container section increases.
Thus, less polymer is formed as the section increases, leading to a higher $T_2$ value, which is converted to a smaller apparent dose via a calibration curve obtained from small calibration vials. The difference is becoming smaller as the depth increase. This is consistent with the above explanation since less dose leads to less polymerization, less heat, and thus the polymerization reaction proceeds to a similar extent in all cases. Overall, these small but meaningful differences are in agreement with recent results from De Deene et al [3] who observed a very small increase of $R_2\ (= 1 / T_2)$ when the temperature of the gels and their environment during the irradiation was increased for similar normoxic dosimeter gels. Since these authors observed a larger increase of $R_2$ for the hypoxic version of this dosimeter, we would predict a larger difference as a function of container dimension will be observed for those gels. It appears clearly that a more complete understanding of these phenomena will require in situ temperature measurements coupled to spectroscopic measurements and theory.

4. Conclusions
In certain cases, inaccuracies in polymer gel dosimetry could be attributed to the calibration procedure where small calibration vials are used to derive a calibration curve that is applied to a larger phantom. Not only could temperature effects lead to relative inaccuracies, but these appear to depend on the absorbed dose.

5. References
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Figure 2. Apparent dose at selected depths for different container sections. The difference between the containers is getting smaller as the depth increases.