# Low-density polymer gel dosimeters for 3D radiation dosimetry in the thoracic region: A preliminary study



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# Low-density polymer gel dosimeters for 3D radiation dosimetry in the thoracic region: A preliminary study

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**Abstract**. Different low-density polymer gel dosimeters have been constructed that can be used to acquire the radiation dose distribution of IMRT treatments in the thoracic region. A heterogeneous phantom consisting of a low density polymer gel dosimeter sandwiched between two layers of soft tissue equivalent gel has been constructed. As a proof-of-principle, the phantom has been irradiated with a square 4 cm × 4 cm beam. The dose distribution is read out by use of both quantitative NMR spin-spin ($R_2$) and magnetization transfer (MT) imaging. Sources of error in the dose readout have been assessed and are discussed.

## 1. Introduction

Gel dosimetry provides a unique feature to display dose distributions occurring in clinical radiotherapy in three dimensions (3D) in humanoid shaped phantoms [1-2]. It has been shown that these polymer gel dosimeters (PGD), have electron densities and stopping powers very close to these of soft tissue [2] and are therefore considered as ideal 3D dosimeters for safeguarding the whole radiotherapy treatment chain.

In a previous study we have also demonstrated the potential to construct low density polymer gel dosimeters by beating the gel to a foam [3]. It was shown by micro-CT that the microstructure of these PGD foams had a very good resemblance to the microstructure of lung tissue. However, it was also shown that as a result of diffusive $R_2$ dispersion by the gas bubbles in the foam, quantitative $R_2$ mapping did not result in reliable dose maps. This was further complicated by practical difficulties in obtaining a homogeneous density distribution in the PGD foam. As an alternative to $R_2$ mapping, quantitative magnetization transfer (MT) imaging was suggested.

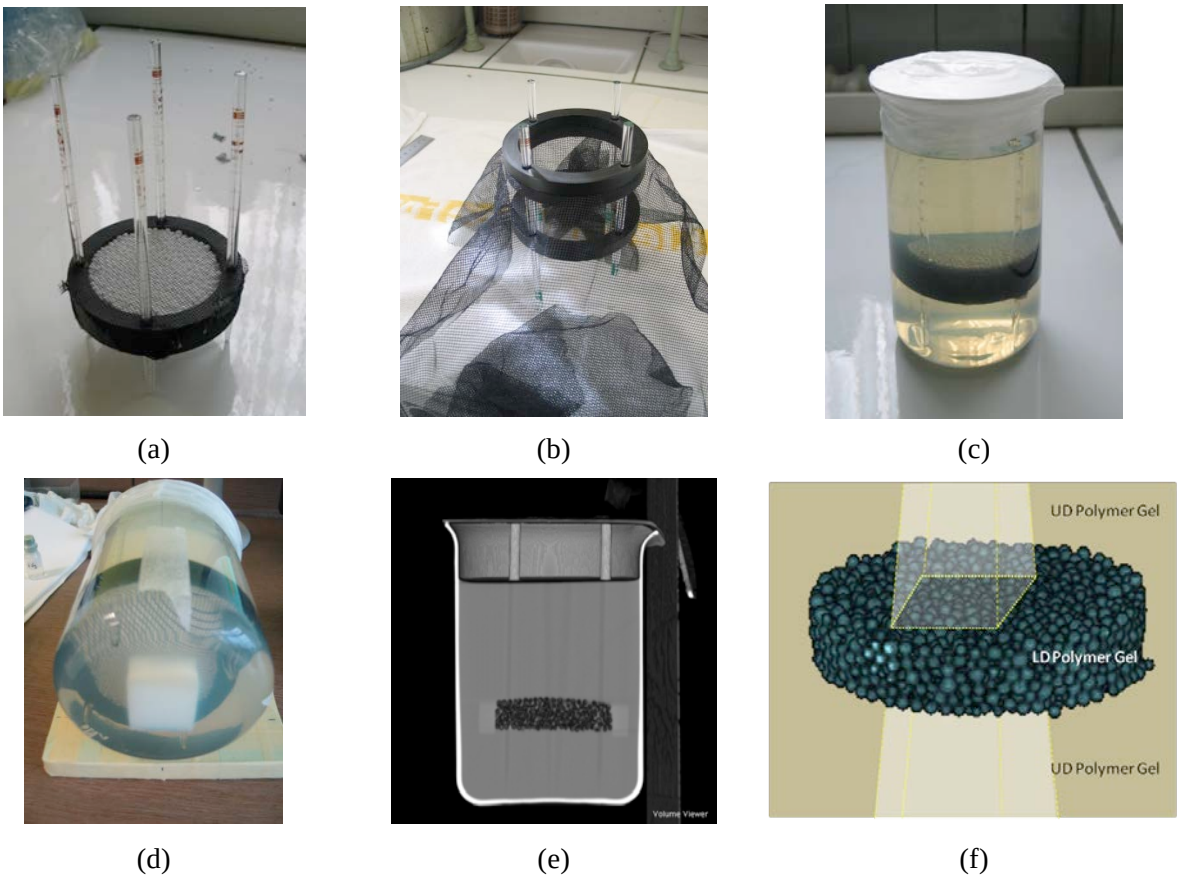
To obtain a more uniform density in the lung equivalent gel dosimeter, we now propose a different strategy by adding Styrofoam beads to a normoxic gel. Before adding gel to the Styrofoam beads, the beads are flushed with nitrogen gas. In addition, the suggested strategy lends itself better to the construction of antropomorphic gel dosimeters consisting of different density layers.

Low density (LD) PGDs could play an important role in 3D radiation dosimetry in the thoracic region (e.g. in the treatment of lung tumors). The construction of the LD PGDs described in this paper, makes it possible to create heterogeneous anthropomorphic 3D dosimeters. The significance of these heterogeneous LD PGDs is exemplified in radiation dosimetry in MRI-Linacs where the electron dose distribution is affected by the magnetic field and in the case of electronic disequilibrium [4].

## 2. Methods and Materials

### *2.1. Low density polymer gel dosimeter construction*

The polymer gel is composed of gelatin (300 Bloom, Type A) [8% (w/w)], methacrylic acid (MAc) [6% (w/w)], bis[tetrakis(hydroxymethyl)phosphonium]sulphate (THPS) [5 mm] and deionized water [approximately 86 % (w/w)]. In this case, Mac was chosen as the radiation active monomer because of its high sensitivity. A high sensitivity is desired to compensate the expected loss in SNR as a result of the lower density. First, gelatin is dissolved and allowed to swell in cold water for approximately 5 minutes. The gelatin mixture is heated to 45°C to bring it in the sol phase. Then, the mixture is allowed to cool down to 32°C after which the MAc is added slowly. In one type of gel, nitrogen is purged through the solution to expel the dissolved oxygen. In other types of gel, no additional nitrogen was bubbled through the solution. In mean time, nitrogen is purged through dry Styrofoam beads for approximately 30 minutes in a desiccator to evacuate the oxygen from the beads. Finally, THPS is added to the solution and is firmly mixed for approximately 3 minutes before pouring the solution in the phantom in which the Styrofoam beads were placed. A three layer phantom was constructed by placing the Styrofoam beads in a cylindrical cavity that was created by use of a nylon wire net (see figure 1). Calibration vials were also fabricated by placing Styrofoam beads in a series of test tubes before pouring the solution. The LD polymer gel had an electron density of 0.4 g/ml.




(a) (b) (c)

(d) (e) (f)

**Figure 1.** Three-layer density phantom with insert containing Styrofoam beads (a). The insert is composed of a nylon wire net that is clamped around Teflon rings that are suspended on glass bars (b). The composed gel phantom before irradiation (c) and after irradiation with a square 4 cm-by-4cm 6 MV photon beam (d). Volume rendered X-ray CT reconstruction of the phantom (e) and a volume rendered reconstruction of the segmented low-density insert with beam indicated (f).

### *2.2. Scanning low density polymer gel dosimeters*

The gel dosimeter phantoms were MRI scanned with multi-spin echo sequences with 32 spin echoes and with different echo time spacings for $R_2$ mapping and with an in house built magnetization transfer (MT) imaging sequence with various MT pulse frequency offsets as described in previous work [4]. All scanning was performed on a Siemens 1.5T MRI scanner (Symphony).

*2.2.1. Computer simulations of $R_2$ dispersion.* The measured $R_2$ values in the low-density gel may be overestimated as a result of diffusive $R_2$ dispersion. This phenomenon has been encountered previously in hydrogel foams and can be turned in an advantage to estimate the bubble size of foam [6]. However, in the purpose of polymer gel dosimetry this is a disadvantage as it affects the $R_2$-dose response differently as in a water-equivalent gel dosimeter. Moreover, uncertainties in readout may arise at the boundary between low-density and unit-density polymer gel. To investigate the dependence of the diffusive $R_2$ dispersion on the size of the Styrofoam beads and on the echo time spacing, computational modelling was performed. The computational model of diffusive $R_2$ dispersion was validated by $R_2$ measurements on a benchtop NMR relaxometer (minispec 0.5T, Brüker) and on a 1.5T MRI scanner.

*2.2.2. Magnetization transfer imaging.* Magnetization transfer imaging was performed on a series of calibration tubes with low density (LD) and unit density (UD) gel irradiated to different doses in order to investigate the magnetization saturation as a function of frequency offset as an alternative to $R_2$ imaging. The MT data was fitted against a two-compartment model assuming a Gaussian line shape for the macromolecular proton pool [5].

## 3. Results and Discussion

### *3.1. Low density polymer gel dosimeter*

The $R_2$ gel measured dose distribution in the three layer phantom is shown in figure 2. The $R_2$ maps were calibrated by using the calibration vials that can be seen on either sides of the phantom (figure 2a). A fair correspondence was found between the gel measured and treatment planning system (TPS) calculated dose distribution. However, a significant deviation with an overestimation in gel measured dose is apparent from the depth-dose profile (figure 2c) in the LD gel as compared to TPS calculated.

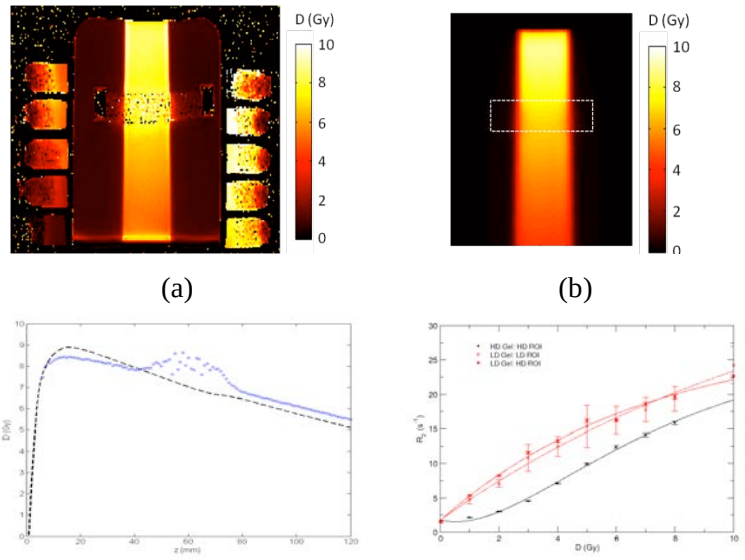
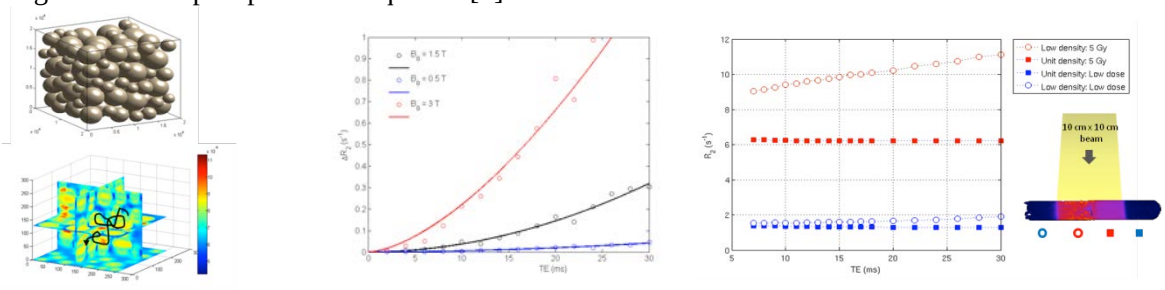



**Figure 2.** Gel measured (a) and TPS calculated (b) dose distribution in the three layer phantom. The depth-dose curve (c) shows a dose overestimation with the PGD in the LD region. The dose-$R_2$ response curve is different for UD and LD gel (d).

The deviation between the $R_2$ measured and TPS calculated dose distribution is attributed to: (1) A difference in oxygen distribution in the MAGAT gel formulation in the phantom and (2) diffusive $R_2$-dispersion caused by the internal magnetic field gradients that result from magnetic susceptibility differences between the Styrofoam beads and the gel fraction.

### *3.2. Diffusive $R_2$ dispersion*

Diffusive $R_2$ dispersion originates from water molecules diffusing in the internal magnetic field heterogeneities will cause an additional nuclear spin dephasing that also depends on the inter-echo spacing of the multiple spin echo sequence [6].

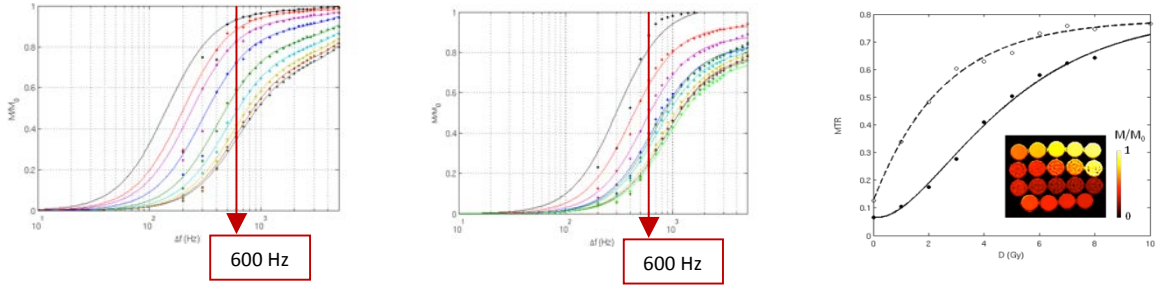



(a) (b) (c)

**Figure 3.** Simulations (a-b) and measurements (c) of the diffusive $R_2$ dispersion in the LD polymer gel dosimeter. The plot in (c) is obtained by scanning a long test tube containing a LD and a UD gel region and which has been irradiated with a lateral 10 cm x 10 cm field as indicated.

### *3.3. Magnetization transfer (MT) imaging*

Magnetization as a function of saturation frequency offset shows that an optimal MTR sensitivity in both a UD PGD and a LD PGD is reached for a saturation pulse frequency offset of 600 Hz (figure 4).




(a) (b) (c)

**Figure 4.** Magnetization as a function of saturation frequency offset for irradiated UD (a) and LD (b) gel samples. An optimum MTR sensitivity is found for $f_{off}$ = 600 Hz. The corresponding MTR dose response shows a similar course as in $R_2$ for both UD (filled symbols) and LD (open symbols) gel.

## 4. Conclusions

Although a too significant discrepancy (approximately 10%) between the dose response in a UD and a LD PGD is found for clinical use, the error sources are well understood and there is room for improvement. There is great potential in using Styrofoam beads to lower the density of polymer gel dosimeters and for both $R_2$ and MT imaging.

## 5. References

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# IC3DDose

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November 4 - 8 , 2012

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