A new polymer gel dosimeter composed of methacrylic acid, agarose gel and THPC with gelatin

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Abstract. In this paper, a new type of methacrylic acid based gel dosimeter is presented. This gel contains both agarose and gelatin with different roles respectively. The agarose conducts itself as a gelling agent, while the gelatin relates to the graft reaction of methacrylic acid. This new type of gel excels in the long-term stability of $R_2$ after irradiation. The characteristics of this gel were studied by the measurements of $R_2$ with MRI and the direct measurements of temperature in the gel during the irradiation.

1. Introduction
The normoxic methacrylic acid (MA) based polymer gel dosimeter (MAG system) has been developed in 2001 (Fong \textit{et al} 2001), and is considered as one of the most standard gel dosimeters so far.

The MAG gel has superior in the sensitivity and resolution to dose, however it has still unstable factors relevant to the dose responses due to the temperature dependence of gelatin’s viscosity. To overcome the difficulties, it is one of solutions to use other gelling agent such as agarose. On the other hand, it has been reported recently that gelatin was the indispensable component to the polymerization reaction as a “trigger” (Hayashi \textit{et al} 2008).

In this paper, we demonstrate the characteristics of a new type of MAG system, which contains gelatin as only a “trigger”, but not as a matrix. In the point of using gelatin to initiate the polymerizations and using agarose as a gelling agent, our gel is essentially different from the conventional MAG system.

2. Materials and methods

2.1. Gel preparation
Table 1 shows composition of gels. In the table, A0.3, G1.0 and M5.0 have same compositions, but just their expressions are different. We used agarose (Agarose S for electrophoresis, Nippon Gene), gelatin (swine skin, 300 Bloom, Sigma Aldrich), MA (99%, wako), tetrakis hydroxymethyl phosphonium chloride (THPC) (80% solution in water, Sigma Aldrich), and distilled water, as component elements of gels.
The procedure of fabricating 500 g gel (0.3% agarose, 1.0% gelatin, 5.0% MA) is shown as following.

- Add 5.0 g gelatin and 1.5 g agarose to 420 g water in a beaker, and wrap it.
- Heat it up with stirring until the solution just starts bumping.
- Cool it down to 40°C in a water bath.
- Add 25.0 g MA, and stir it for 15 minutes.
- Add 180 µl THPC solution dissolved in 48.5 g water, and leave it for 1.5 minutes with stirring.
- Divide it into small containers (approximately 50 ml glass vial).
- Store the divided samples in an incubator at 23°C (same temperature as MRI room) for one day.

Table 1. Composition of polymer gel dosimeters. All values (except THPC) represent weight percentages. In the expression of the sample, “A”, “G” and “M” stand for the concentration of “agarose”, “gelatin”, and “MA”, respectively. And the variations in the concentration are shown in bold.

| Chemical | A0.2, A0.3, A0.4 | G0.5, G1.0, G2.0, G3.0 | M2.0, M3.0, M5.0, M7.0 |
|----------|------------------|------------------------|------------------------|
| Water    | 93.6 – 93.8%     | 91.7 – 94.2%           | 91.7 – 96.7%           |
| Agarose  | **0.2 – 0.4%**   | 0.3%                   | 0.3%                   |
| Gelatin  | 1%               | **0.5 – 3%**           | 1%                     |
| MA       | 5%               | 5%                     | **2 – 7%**             |
| THPC     | 2 mM             | 2 mM                   | 2 mM                   |

2.2. Gel irradiation
The gel samples were irradiated to 6 MV photon beam of a medical linear accelerator (EXL12SP, Mitsubishi) in a water phantom at 100 cm SSD, the top surface of vials was set at the same level of water surface. The samples were irradiated 0 - 15 Gy for the study of dose-R\(_2\) response relations.

2.3. MR imaging
All images were acquired with 0.3 T open MRI system (AIRIS-II comfort, Hitachi) using a multiple spin-echo sequence. All of dose-R\(_2\) response curves were acquired after one day post-irradiation. The long-term stability of R\(_2\) in A0.3 was examined by the acquisitions at 3 - 240 hours post-irradiation.

2.4. Temperature measurements
The probe of a digital thermorecorder (TR-52, T&D) was inserted into the gel. The variations in the temperature of the gel owing to exothermic reactions were recorded every two seconds from the start to after the irradiation.

3. Results and discussion
Figure 1 shows dose-R\(_2\) response curves of all gels in this experiment. All of gels have the non-liner dose-R\(_2\) response curves. In Figure 1(a), each dose-R\(_2\) curve is constant in its shape, while the absolute value of R\(_2\) increases as the concentration of agarose increases. And the maximum variation in the gel’s temperature is almost same irrespective of agarose concentration, as Table 2 shows. These results show that the agarose would not participate in the polymerization reaction, but just conduct itself as a gelling agent.

On the other hand, with increasing gelatin concentrations, the gradients of dose-R\(_2\) response curves increase at the high dose region [Figure 1(b)] and the gels’ maximum variations in temperature increase [Table 2]. With increasing MA concentrations, the gradients of dose-R\(_2\) response increase slightly at the low dose region [Figure 1(c)] and the gels’ maximum variations in temperature also increased [Table 2].
Above experimental results can be explained as follows. In the case of low gelatin concentration, the graft reaction of MA on gelatin occurs to some extent at the low dose region. As a result, the relatively large variation in $R_2$ is found (the reaction might cause larger structural change of gelatin molecule). After the consumption of gelatin, the MA propagation reaction is then predominant at the high dose region. The resulting MA polymers cause small variation in $R_2$. On the other hand, with increasing gelatin concentration, the reaction between gelatin and MA is still predominant at the higher dose region and steep gradients of the dose-$R_2$ response are obtained. The excessive amounts of MA over gelatin in M5.0 might be consumed in the propagation reaction. As a result, the maximum variations in temperature of M7.0 would be larger than that of M5.0.

Figure 2 shows a long-term stability of $R_2$ in A0.3 after irradiation. The $R_2$ of this gel is much less dependent on the post-irradiation time than that of the standard MAG system (De Deene et al 2006). The reason of this stability is interpreted that the agarose in this gel would not participate in the polymerization reaction. It is the advantage of agarose as a gelling agent.
Figure 1. Dose-R$_2$ response curves for A0.2 - A0.4 (a), G0.5 - G 3.0 (b) and M2.0 - M7.0 (c).

Table 2. Maximum variations in temperature with 5 Gy irradiation.

|          | A0.2 | A0.3 | A0.4 | G0.5 | G1.0 | G2.0 | G3.0 | M2.0 | M3.0 | M5.0 | M7.0 |
|----------|------|------|------|------|------|------|------|------|------|------|------|
| Temperature (°C) | 2.1  | 2.2  | 1.9  | 1.6  | 2.2  | 2.5  | 2.6  | 0.7  | 1.1  | 2.2  | 2.7  |

Figure 2. The long-term stability of R$_2$ in A0.3.

4. Conclusion
In this study, we investigated the characteristics of a new MAG type polymer gel dosimeter using agarose as a gelling agent. The dose-R$_2$ response is comparable with that of the conventional MAG system and the thermal stability is superior. Our gel appears to be a promising dosimeter because it minimizes both the structure relaxation of gelatin at storing and the melting of the gel by the exothermic polymerization reaction. Further studies on developing of the more stable dosimeters using combination of gelatin and the other gelling agents are undergoing in our group.

References
[1] Fong PM, Keil DC, Does MD, Gore JC 2001 Polymer gels for magnetic resonance imaging of radiation dose distributions at normal room atmosphere. Phys. Med. Biol. 46 3105-13
[2] S Hayashi, M Yoshioka, S Usui et al. to be appeared in this conference
[3] De Deene Y, Vergote K, Claey C, De Wagger C 2006 The fundamental radiation properties of normoxic polymer gel dosimeters: a comparison between a methacrylic acid based gel and acrylamide based gels. Phys. Med. Biol. 51 653-73