Alternative gelling agents for normoxic gels: a stability study

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1. Introduction
In 2001 Fong et al [1] published the first paper on normoxic gels. Until that moment, polyacrylamide gelatin gels (PAG) where the most frequently used radiation sensitive polymer gels. In contrast to the PAG gels, normoxic gels can be produced in normal atmospheric conditions. This is obtained by adding an anti-oxidant to the gel. The anti-oxidant scavenges the oxygen in the gel which is an inhibitor for free radical polymerization.

In 2002 De Deene et al [2] reported that the dose response curves of several polymer gel dosimeters including normoxic gel dosimeters were instable with time. This was ascribed to two effects. First of all, the polymerization reaction does not stop immediately after irradiation. It continues until about ten hours after the irradiation causing a drift in the slope. Secondly, the gelling of gelatin also continues which causes a drift in the R2 value.

In this paper the influence of the use of alternative gelling agents on the dose response curve of normoxic gels is investigated. Part of the experiment is still in progress.

2. Materials and methods

2.1. Production of the gels
Six different gels were fabricated: gelatin A (6%(w/w)), gelatin B (10%(w/w)), agarose (1%(w/w)), pectin (6%(w/w)), satiagel (2%(w/w)) and satialgine (2%(w/w)). Methacrylic acid (3%(w/w)) and hydroxyethylmethacrylate (3%(w/w)) were used in combination with gelatin A. This radiation-sensitive gel will be referred to as HEMA in this paper. Methacrylic acid (6%(w/w)) was added to all other gelling agents.

The gelling agents were dissolved in the total water volume and heated to about 45°C, except for agarose which was heated to about 80°C. The monomers were added to the gelling agent solution after a clear solution was obtained at 35–40°C. Tetraakis hydroxyethylphosphoniumchloride (THP) (2mM) was used as anti-oxidant. THP was added to the monomer-gel solution just before filling the tubes.
2.2. Irradiation of the gels

Each of the gel tubes were irradiated in a water tank with the axis of the tubes perpendicular to the beam axis and irradiated with 6 MV photons at a depth of 5 cm and respecting a source-to-surface distance (SSD) of 95 cm. A dose rate of 4 Gy min$^{-1}$ was used.

2.3. MR scanning of the gels

All tubes were placed together in a Siemens Symphony 1.5T whole body scanner using a standard CP head coil. A slice selective multiple spin-echo sequence was used with a CPMG pulse scheme and 32 equidistant spin-echoes (TE/TR/FOV/MS= 20 ms/5s/180mm/192).

3. Results

In a dose interval of 0 to 20 Gy, R2 changes 2.9 s$^{-1}$ for agarose (figure 1a), 19.2 s$^{-1}$ for gelatin B (figure 1b), 15.6 s$^{-1}$ for HEMA (figure 1b), 0.69 s$^{-1}$ for satiagel (figure 1c) and 0.75 s$^{-1}$ for satialgine (figure 1c). No change in R2 was found for the pectin gel.

![Figure 1. R2 versus dose plots of the different radiosensitive gels approximately 266 h after irradiation. (a) agarose, (b) HEMA and Gelatin B, (c) Satialgine and Satiagel](image-url)
Figure 2a shows the slope of the linear part of the $R_2$-dose curve as a function of the post-irradiation time. Except for HEMA all the radiation sensitive gels have reached a constant slope value after 40 hours. Gelatin B and HEMA have the highest slope values around respectively $1.03 \text{ Gy}^{-1} \cdot \text{s}^{-1}$ and $0.7 \text{ Gy}^{-1} \cdot \text{s}^{-1}$. The slope of agarose, satiagel and satialgine were much lower amounting respectively $0.11 \text{ Gy}^{-1} \cdot \text{s}^{-1}$, $0.038 \text{ Gy}^{-1} \cdot \text{s}^{-1}$ and $0.034 \text{ Gy}^{-1} \cdot \text{s}^{-1}$.

![Figure 2a](image)

Figure 2b shows the $R_2$ value of the unirradiated radiation sensitive gel ($R_{20}$). Except for HEMA all the radiation sensitive gels reached a constant $R_{20}$ value after 40 hours. HEMA shows an increase of $R_{20}$ as a function of time. Agarose has the highest $R_{20}$ around $12.1 \text{ s}^{-1}$. HEMA has the second highest $R_{20}$ around $5.76 \text{ s}^{-1}$. Satiagel and satialgine have comparable $R_{20}$ around respectively $2.22 \text{ s}^{-1}$ and $2.23 \text{ s}^{-1}$. Gelatin B has the lowest $R_{20}$ around $1.44 \text{ s}^{-1}$.

![Figure 2b](image)

**Figure 2.** The course of the slope (A and B) and the $R_{20}$ (C and D) of the different radiation sensitive gels as function of the post-irradiation time
4. Discussion and conclusion

The slope of agarose gel (figure 1a), which is a measure for the dose sensitivity of the gel, has a rather low value of 0.11 Gy⁻¹.s⁻¹. Considering this low sensitivity and the high R₂₀-value (which implies a low dose resolution [3]), agarose is not a worthy alternative for gelatin A in the production of normoxic gels. The course of the R₂-dose curve of gelatin B is comparable with that found for PAG and methacrylic acid based normoxic gelatin gel dosimeters (MAG). It has a non-linear behavior in the low dose (< 2 Gy) and in the high dose region (> 10 Gy). In the middle dose, region it shows an approximately linear behavior. Gelatin B has high dose sensitivity (slope 1.03 Gy⁻¹.s⁻¹). The low R₂₀-value of gelatin B is related to the fact that gelatin B has become liquid during the experiment. The R₂-dose curve of HEMA shows a different course compared to gelatin B, especially in the low dose region. HEMA shows a decrease of the slope as a function of the time and an increase of the intercept with time. This is in agreement with the course of the slope and the R₂₀ of normoxic MAG dosimeters [2].

Satiagel and satialgine show very low dose sensitivity. Their R₂-dose curves are similar although satialgine became liquid during the experiment. A bi-exponential course is found, which is similar to the course of other normoxic MAG dosimeters [2]. Pectin gel did not show any response (data not shown).

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