Study of density and stability of a lung-equivalent gel

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1. Introduction

Gel dosimetry is a useful tool for the verification of radiation treatments in water-equivalent tissues. In order to extend the application of gel dosimetry to the lung, the density of the dosimeter should be reduced. Some methods have been proposed for the fabrication of low-density gels. Major challenges in the fabrication of these gel dosimeters are to achieve a density that equals the electron-density of lung tissue and to obtain an acceptable homogeneity. Both polymer ([1], [3]) and Fricke ([2], [4]) gel formulations have been used as basic chemical compositions for low-density gel dosimeters. To reduce the density, two approaches have been suggested: (1) Styrofoam beads can be added to the gel or (2) the gel can be beaten until a foam is obtained. In this study we followed the latter method and added sodium-dodecyl-sulphate (SDS) as a surfactant to increase the surface tension of the gel. The amount of SDS was varied between 0.0% (w/w) and 1.5% (w/w) in order to tune the density. Other parameters such as the temperature and the time of mixing during fabrication were also found to have a significant influence on the resulting density and homogeneity of the gel. In addition, a temporal stability study was performed during a period of one week.

2. Materials and methods

The polymer gel foam dosimeter is composed of gelatin (300 Bloom, Type A) (12% (w/w)), methacrylic acid (MAc) (6% (w/w)), sodium-dodecyl-sulphate (SDS) (0.0-1.5 % (w/w)) and Bis[tetrakis(hydroxymethyl)phosphonium]sulphate (THPS) (10 mM) and de-ionized water (approx. 82% (w/w)). All chemicals were purchased from Sigma-Aldrich. A relatively large concentration of gelatin is used to compensate for the loss of gel strength caused by the addition of methacrylic acid at higher temperature. Although the gelatin solution has already a high foaming capacity by itself, the addition of the surface active SDS is needed to lower the density in order to approximate the density of lung tissue. To remove traces of oxygen, THPS is added. It was also found that the gel sets more rapidly in the presence of THPS at concentrations of 10 mM and higher.

The relation between SDS and the resulting density was investigated on the bench-top in normal atmospheric conditions. For the stability study, the solutions were placed in a nitrogen-flushed glove box. The oxygen concentration in the glove box was monitored with dissolved oxygen meters (Oxi 325, WTW).

In constructing the gel foam, the total amount of water was subdivided in three portions. The gelatin (12% (w/w)) was dissolved in 50% of the total amount of water at room temperature (approx. 22°C). After swelling of the gelatin powder for about 15 minutes, the gelatin solution was heated to 45°C in order to jellify the gel. The MAc was dissolved in 30% of the total amount of water and kept at room temperature. An SDS solution was made with the remaining part of the water (approx. 13%) by stirring manually. The gelatin solution was then cooled down to 35°C while stirring magnetically. At that temperature, the gelatin solution becomes very viscous and the MAc solution is added. The solution is magnetically stirred for about half a minute to make it homogeneous. The magnetic
stirrer is then removed and the gel is beaten by use of a household mixer. The SDS solution is then added. The gel is beaten for another 3 to 4 minutes until a white viscous creamy foam liquid is obtained. Then the THPS solution is added while still beating the gel. After another minute, the gel foam is poured into the recipients. Calibration vials with an opening of 2 cm were also filled. After filling the recipients, they are mounted into a block of Styrofoam that is rotated at a rate of 3 rotations per minute in order to avoid inhomogeneous drainage during setting of the gel foam. The recipients are left to rotate for a minimum of 5 hours before being irradiated and/or scanning.

The B1-field inhomogeneity was measured for a non-irradiated gel. The relation between the spatial distribution of the flip angle and the signal intensity of the different images (R2 and MT) was translated to an equation. This equation was used to correct the images made during the research. To obtain a H-proton density image the S0-image was used. The S0-image is derived by using the intercept of the T2-decay curve of each pixel. In order to calibrate the S0-image, a large test tube with de-ionized water was used. The obtained proton density in the S0-image is relative to the proton density of water ([1]). All density values mentioned in this paper are proton densities relative to water.

3. Results

In figure 1 the relation between the SDS concentration and the resulting proton-density is shown. Even without addition of SDS a proton density relative to water of 0.35 is obtained. To obtain a proton density relative to water of 0.3, equivalent to the proton density of lung tissue, SDS has to be added.

The stability of the lung-equivalent gel dosimeter was investigated by scanning the gel foam at 5 different moments in a time span of a week. The foam was irradiated 5 hours after production and scanned 1, 2, 3, 5 en 7 days later. R2-dose response curves and MT-dose response curves were recorded. The lung-equivalent gel dosimeter is found to be stable (figure 2).

![Figure 1. Gel foam density as a function of SDS concentration.](image-url)
Figure 2. Dose-R2 response (a) and dose-MT response as a function of post-irradiation time.

For the lower dose values there is a small increase of signal intensity with post-irradiation time in the MT-images while for the higher dose values the signal intensity however remains the same with post-irradiation time.

Figure 3. Structural and stochastic noise in gel foam dosimeters containing different SDS concentrations

Figure 3 shows the noise level in the proton density images. The stochastic noise is independent on the SDS concentration. This can be expected since all measurements were performed with the same imaging parameters. The structural noise is found to be independent of the SDS concentration and is within the range of 4 to 10% relative to the proton density. The lung-equivalent foam in this study can therefore be considered as homogeneous. Four out of 19 gel foams that contained severe heterogeneities (large air bubbles and gelatin clots), were not included in this study.
4. Discussion and conclusions
A low-density gel dosimeter can be obtained by beating a polymer gel solution to a foam. Without additives a proton density relative to water of 0.35 can be achieved. The surfactant SDS can be used to lower the density even further. In this study, a relation between proton density and SDS concentration is derived. It was also found that the temperature history of the gel during fabrication has a significant influence on the formation of larger air bubbles and clots of gelatin in the gel. The precise mechanism behind these heterogeneities has not yet been resolved. We believe that a good temperature control and a standardized (automated) manufacturing process are beneficial to the homogeneity of the gel foam dosimeter. The foams were homogenous in density. An acceptable stability is found for both R2 and MT in the irradiated gel foam dosimeters in a time span of one week.

5. References
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