Radiation dosimetry in lung equivalent regions by use of polymer gel foams and quantitative magnetization transfer imaging

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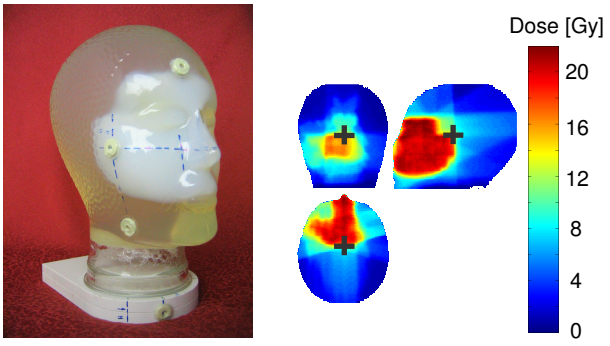
Introduction

The ultimate goal of conformal radiotherapy is to tailor the delivered radiation dose distribution to the shape of the tumor. To verify the delivered dose distribution in three dimensions, several polymer gel dosimeters have been developed. These polymer gel dosimeters consist of a gel in which monomers are dissolved. Upon irradiation a radiation induced polymerization reaction occurs of which the degree of polymerization is proportional to the absorbed dose. The spin-spin relaxation rate (R2 = 1/T2) is correlated with the degree of polymerization. As a result, the spatial dose distribution can be obtained by R2 mapping. This technique has been successfully adapted for the verification of intensity modulated radiotherapy treatments (IMRT) in soft-tissue regions [1]. However, because of the lower electron density in lung-tissue the radiation induced interactions occur at different spatial scales as compared to water-density equivalent tissue. As a result, the dose distribution in lung can not be verified with the existing polymer gel dosimeters. For this purpose, a lung-tissue equivalent gel dosimeter is proposed. The gel is basically a foamed polymer gel with a density between 0.25 and 0.35 kg/dm^3. R2 images are acquired from the radiation sensitive gel foam that are subsequently converted to dose maps using calibration vials. It was found that the measured R2 is more susceptible to the microstructure of the gel foam due to susceptibility differences between the nitrogen bubbles and the interstitial gel phase. Magnetization transfer is another NMR contrast mechanism that is determined by the exchange of magnetization between different H-proton pools. The use of MT imaging for polymer gel dosimetry has been previously proposed [2]. The MT contrast in polymer gel dosimeters is achieved by the saturation of the H-protons of the polymer. The change in MT frequency dispersion upon polymerization (ionizing irradiation dose) is illustrated. From this study, it is concluded that MT imaging is less sensitive to the foam microstructure (bubble size) than R2 mapping.



(a) (b)

Figure 1. Gel phantom irradiated according to a conformal radiotherapy treatment (a). The white region is due to irradiation induced polymerization. Maps of absorbed radiation dose are obtained by use of high-accuracy quantitative R2 imaging (b).

Materials and Methods

The polymer gel foam is fabricated along a procedure described elsewhere [3]. The sol is beaten with a household mixer until a creamy white viscous foam is obtained. Then the gel foam is poured into the final recipients and is placed in a rotating device and rotated during at least 5 hours during solidification. All gel foam dosimeters were irradiated with high energy photon beams (6 MV). Calibration test tubes were irradiated at known reference doses. Quantitative R2 images of the gel foam phantoms were obtained using a CPMG-based multiple spin-echo sequence on a 1.5 T MR scanner (Siemens, Symphony) equipped with a CP head coil. MT images were acquired using a home-written imaging sequence based on a spin-echo readout preceded by a train of Gaussian-shaped saturation pulses of which the number and the offset frequency can be varied. The electron density and proton density were obtained by use of CT and proton-density MRI. In order to calibrate the proton density images a set of test tubes containing different concentrations of deuterium and water were used.

Results and discussion

The signal attenuation caused by magnetization transfer is dependent on both the number of saturation pulses and the frequency offset of the saturation pulses with a maximum dose sensitivity around 700 Hz (figure 2a). A clear correlation between the MTR and the absorbed dose in the gel sample is found (figure 2b). MT images and corresponding dose images are shown in figure 2c-d for some gel phantoms. R2 images of the same gel foam phantoms were also obtained (not shown). It was found that the MT images were less dependent on the foam microstructure than the R2 images. Bubble size related R2-relaxation dispersion was found in the gel foam. The relaxation dispersion is attributed to the magnetic susceptibility difference between the gel phase and the air bubbles in the foam. This susceptibility difference causes microscopic magnetic field gradients that cause diffusion-related attenuation of the MR signal. The diffusion-weighting is proportional to the echo time spacing (TE = 2τ). It was also found that coarsening of the gel foam over time had a significant influence on the R2 relaxation dispersion. A detailed study of the correlation between foam microstructure and R2 relaxation dispersion will also be presented at this conference.

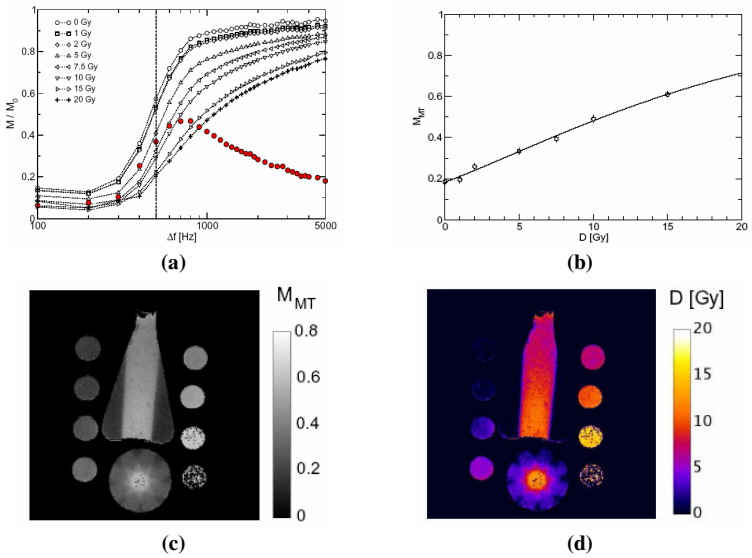


Figure 2. (a) Magnetization transfer as a function of the offset frequency of the saturation pulses for gel foam samples irradiated to different doses. A difference curve of the 0 Gy and 20 Gy sample is also shown. A dose-MT response curve is shown in (b) obtained at a saturation pulse offset frequency of 500 Hz. Resulting MT image (c) and corresponding dose image (d) of some foam gel dosimeters. The upper Erlenmeyer is irradiated with a 4 cm-by-4 cm photon beam. The phantom in the lower part of the image is irradiated with 4 small photon beams (1 cm-by-10 cm) at angles of 45 degrees with respect to each other.

Conclusions

A polymer gel foam is introduced as a potential three dimensional integrating dosimeter for the verification of absorbed dose distributions in the lung. This study showed that magnetization transfer imaging might be preferable to R2 imaging for dose verification. Diffusion-related relaxation dispersion that is characteristic for the foam microstructure has been observed in the gel foam dosimeters. From this study, it is also found that R2 dispersion characteristics provide an interesting tool for microstructure analysis of air-filled cavities in foam-like structures.

References

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