Three dimensional radiation dosimetry using polymer gels

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Abstract

The use of polymer gels to record radiation dose distributions in three dimensions was first proposed in 1992 as a proof-of-principle [1]. The accuracy of these early polymer gel dosimeters and scanning methods was not sufficient for most clinical applications [2]. Since then, several efforts were made to increase the accuracy and precision of both the physical gel dosimeter and the scanning technique [3,4]. Different read out techniques have been investigated. Magnetic resonance imaging was soon followed by optical scan techniques [5-7] and X-ray CT [8]. The potential applicability of polymer gel dosimeters has been shown for a variety of applications such as for dose verification in conformal radiotherapy [9], brachytherapy [10], proton therapy [11], boron neutron capture therapy [12] and diagnostic X-ray CT [13]. The polymer gel composition can be optimized for each application. The complete dosimetric performance with respect to dose rate insensitivity, temperature insensitivity, temporal stability, dose integrity and energy sensitivity has only been determined for a few polymer gel compositions [14,15]. The large variety of polymer gel compositions and scanning methods may explain why so little polymer gel dosimeters are currently used in everyday radiation quality assurance. Current efforts are directed towards less-toxic polymer gel dosimeters and alternative scanning techniques that could be easily implemented by the radiation physicist.

Polymer gel dosimetry

Gel dosimeters are radiation sensitive chemical dosimeters that aim at displaying the integrated absorbed dose in three dimensions (3D). Basically, gel dosimetry involves three steps: First, the radiation sensitive gel is fabricated in a chemical laboratory. Polymer gel dosimeters consist of a hydrogel in which monomers are dissolved. Upon fabrication, the gel solution can be poured in a plastic cast with an anthropomorphic shape (figure 1a) or in a recipient that can be suspended in an anthropomorphic shaped carrier phantom. Second, the 3D gel phantom is irradiated. Upon irradiation, a radiation induced polymerization reaction occurs in which the amount of created polymer is related to the absorbed dose. The polymer structures are fixed by the gelatin matrix. Thirdly, the gel dosimeter is read out by use of a dedicated quantitative imaging technique. A frequently used imaging technique is magnetic resonance imaging (MRI). This is based on the fact that the spin-spin (T2) NMR relaxation time in a polymer gel decreases with increasing amounts of polymer. After calibration a set of dose images is obtained (figure 1b). Several methods to compensate for MR imaging artifacts that compromise the accuracy in the dose images have been developed [3]. A small change in mass density in polymer gels upon irradiation is responsible for a measurable change in Hounsfield units which enables the use of X-ray CT to read out polymer gel dosimeters [13]. In order to gain sufficient signal-to-noise, several image averages are required. In this context, attempts have also been made to increase the signal-to-noise ratio by adequate image filtering [16]. The change in optical opacity has also lead to the development of optical scan techniques [7]. Basically, optical scan techniques use a methodology similar to X-ray CT but with an optical laser beam instead of an X-ray tube and by
rotating the dosimeter on a rotational stage with respect to the laser and detector instead of rotating the source and detector. Back projection of the scanned profiles is used to reconstruct an optical density image.

**Applications of polymer gel dosimetry**

Polymer gel dosimeters are particularly useful in recording integrated dose distributions with steep dose gradients in three dimensions that may often be encountered in conformal radiotherapy. Polymer gel dosimeters have also been evaluated for treatment verification of brachytherapy but some limitations have been addressed for point irradiation sources [17]. Polymer gel dosimeters potentially allow also to be doped with other chemical agents such as Iodine to increase the dose effect when irradiated with low-energy X-rays. Polymer gel dosimeters with decreased electron density can be obtained by beating the gel to foam in order to simulate lung tissue (figure 2). A new MRI scan technique (magnetization transfer imaging) had to be developed to read out the dose distribution of these low density gel dosimeters [18]. The use of polymer gel dosimetry for high-LET radiation dosimetry has also been investigated. However, it is shown through Fourier transform Raman spectroscopy and track structure calculations that saturation effects occur in the vicinity of high LET tracks for current polymer gel dosimeters reducing the radiochemical effectiveness [19].

In the case of 3D gel dosimetry, accuracy and precision should be evaluated in terms of dose and space [20]. In the final measured 3D dose distribution, the spatial and dosimetric dimensions are interwoven. Various error sources that occur at different stages of a gel dosimetry experiment can compromise the overall accuracy and precision. In optimizing 3D gel dosimetry, a profound accuracy study is required at all stages. An “idea” on the overall accuracy can be acquired by comparison with other (one and two dimensional) dosimetry methods.

Several new gel formulations have been proposed but, until now, only a few have been tested thoroughly with respect to their radiation properties (such as dose rate dependence, energy dependence, spatial integrity and temperature dependence). It is expected that a better understanding of the chemistry of polymer gel dosimeters will result in gel dosimeters that are “tuned” for specific applications and that are less toxic.

Optical CT scanning may become a useful alternative to read out 3D dosimeters. Several prototypes of optical CT scanners have been constructed. New kinds of transparent plastic dosimeters have been proposed. In these plastic dosimeters a leucodye is dissolved. Upon irradiation a color change occurs that is proportional to the absorbed dose. The plastic dosimeters can be scanned by use of an optical scanner [21].

![Figure 2. Low density polymer gel for dosimetry in lung regions. The low density polymer gel is basically a hydrogel foam as can be seen from the micro-CT image (a). The size of the bubbles is in the range of 0.1 to 1 mm. An Erlenmeyer and calibration tubes filled with polymer gel foam are irradiated with a 4-by-4 cm photon beam (b) and scanned with magnetization transfer MRI (c).](image)
Figure 3. Optical CT scanning of polymer gel dosimeters. Photographs (a) and principle scheme (b) of the homebuild UGent optical CT scanner prototype. A scanning laser beam moves through a gel phantom which is mounted on a rotational stage within a fluid bath. Transmission profiles are acquired for each rotational increment of the phantom. The phantom is mounted on a linear stage that can move downward to acquire different slices. An optical density 3D image of a test phantom containing a stack of needles (shown in c) is acquired (d).

References


Note

More information and presentations can be downloaded from: http://krtkg1.ugent.be/KrtkgHomepage/QM-NMR/