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2006 J. Phys.: Conf. Ser. 56 283

(http://iopscience.iop.org/1742-6596/56/1/050)

Institute of Physics Publishing
doi:10.1088/1742-6596/56/1/050

Journal of Physics: Conference Series **56** (2006) 283–285
4th International Conference on Radiotherapy Gel Dosimetry

Read-out of radiosensitive gels with ultrasound elastography: technique description and preliminary studies

Remo Crescenti, Jeff Bamber, Nigel Bush, and Steve Webb

Joint Department of Physics, Institute of Cancer Research and Royal Marsden NHS Trust, Sutton, Surrey, UK

1. Introduction

Ultrasound methods to read dose distributions from radiosensitive gels have been proposed as a low cost alternative to the conventional read-out with magnetic resonance imaging. Previous work [1] showed a dose dependence of the speed of sound and ultrasound attenuation for different formulations of gels. Such properties depend largely on the bulk elastic modulus, the density, and molecular relaxation mechanisms initiated by the acoustic modulation of pressure, density and temperature. Since radiation-induced polymerisation generates longer molecules or even cross-links between molecules, it might be expected that elastic properties like the shear elastic modulus or Young's modulus would be useful alternative properties to investigate as read-out parameters. Furthermore, recent progress in the field of medical ultrasound elasticity imaging [2] has demonstrated that various algorithms can track ultrasound echoes from tissues during the application of a small external stress resulting in real-time images of the medium deformation (strain). This may be done in three dimensions. It appears therefore that all components of a future read-out technique based on elastic properties are coming into place.

This abstract reports early work towards such an objective, in particular our preliminary studies of Young's modulus of homogeneously irradiated cylindrical gel samples.

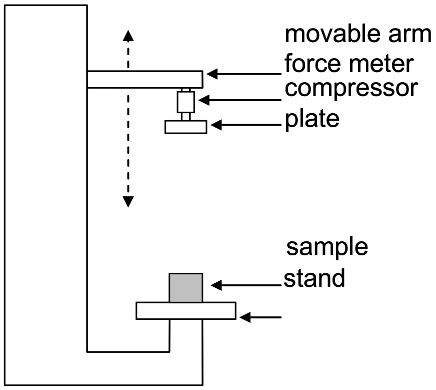

Figure 1. Functional components of the mechanical testing apparatus

2. Material and Methods

Specially designed and constructed cylindrical polymethyl methacrylate (PMMA) containers with removable tops and bottoms provided a suitable shape for the samples to be tested. The use of a normoxic gel composition simplified the filling process. MAGIC gel [3] was employed because of the low toxicity of its components compared to gel formulations such as the carcinogenic and more toxic acrylamide gels, making it safer to handle without containment. Three gel batches with 6 samples and one with 12 samples were produced.

The homogeneously irradiated samples were compressed with an Instron 3342™ mechanical testing device, producing force and displacement data (see figure 1). Young's modulus was obtained by calculating the slope of a linear fit to data of measured stress versus applied strain.

3. Results and Conclusions

The Young's modulus monotonically increased with increasing dose up to 40 Gy in an approximately linear way. Batch dependence as well as intra-batch variability was pronounced in these preliminary results. Figure 2 shows two of the batches with doses up to 20 Gy and 40 Gy respectively. The other two batches (not shown, for clarity) produced values from about 3 kPa (4 kPa) at 0 Gy up to 31 kPa (24 kPa) at 40 Gy (35 Gy). Batch dependence has been observed with other, more established, gel dosimetry read-out methods such as MRI. Here it is largely due to the different temperatures at which the experiments were carried out. The intra-batch variation is something that is currently being explained through separate experiments not reported here, but currently it appears to be largely due to a combination of limited temperature control, loss of water from the gel by evaporation during measurement and imperfect boundary conditions for the gel samples being tested. The elastic properties of the gels are highly sensitive to temperature (a change of possibly more than 10 % per °C at 21 °C) while the temperature was only controlled to within ± 0.5 °C. The gel had to be removed from the container for testing but it tended to stick to the cylinder, top, and bottom. This caused some damage at the surface of the sample and even a deep crack in two of the samples. Furthermore, it was difficult to maintain consistently slippery interfaces between the gel and the stand, and the gel and the compressor plate. Finally, separate experiments have shown that, after removal of the gel samples from the containers, Young's modulus decreases at the rate of 0.5 % per minute, due to loss of water

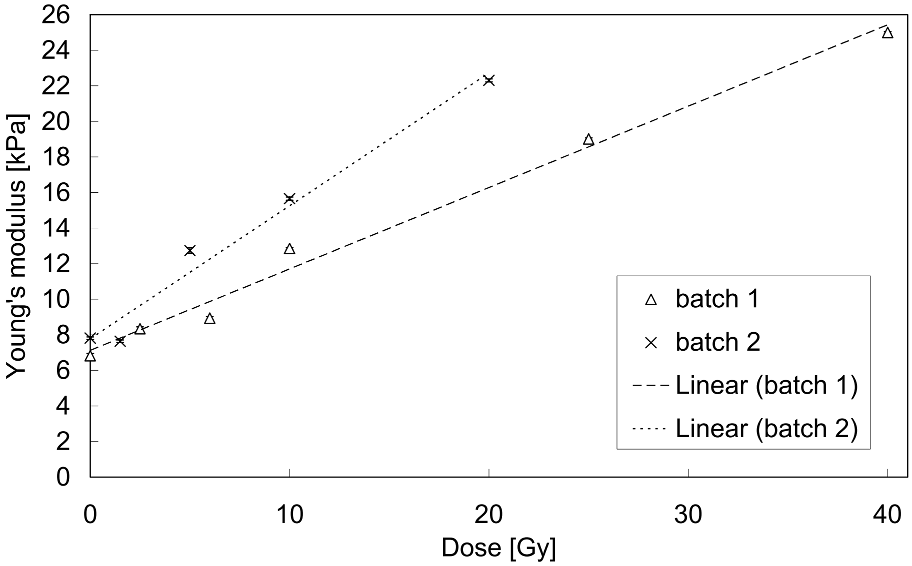

Figure 2. Measured Young's modulus as a function of radiation dose for the two gel batches described in the text.

by evaporation. For the measurements that resulted in the data shown in figure 2 attempts were made to standardise the time between removing the gel from the container and measuring Young's modulus. The measurement of the sample with 1.5 Gy dose (batch 2) was, however, interrupted and it consequently lost substantially more water than the other gel samples. This data point only, therefore, has been corrected using an estimate of the excess measurement delay and the above factor for the rate of change in Young's modulus due to loss of water.

4. Current and Future work

Current work aims to further explain the inter- and intra-batch variations and reduce them to a useful level. Our experiments to date suggest that this ought to be possible.

This simple compression technique allows Young's modulus to be measured in homogeneous samples, but the global force and displacement data are not enough information to calculate the local elastic modulus in inhomogeneously irradiated gels (e.g. IMRT verification). Under compression, stiffer regions in the gel surrounded by softer areas will be compressed less than their surrounding and vice versa. Local displacements may be measured by tracking echoes in ultrasound images acquired during the compression. This can be done with gels that have been modified to make them scatter ultrasound, and with an ultrasound transducer built into the compressor plate, and therefore obtaining images along the direction of compression. High density polyethylene granules with a mean diameter of 119 μm (0.34 % w/w) could be added to the gel formulation to produce a homogenous ultrasound backscattering speckle pattern throughout the gel, independent of the pattern of irradiation. Tracking of speckles on frames acquired at different times would show the local displacement within the gel. With the local displacement information a local strain image (elastogram) can be calculated. Together with the force data on the surface the local strain can, in principle, be used to calculate the local elastic modulus by solving the inverse elasticity problem (e.g. [4]).

It would therefore appear that the elastic properties of radiation sensitive gels may provide promising read-out variables and deserve further study and development.

5. References

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