Physics in Medicine & Biology

IPEM Institute of Physics and Engineering in Medicine

LETTER TO THE EDITOR

Comment on `A systematic review of the precision and accuracy of dose measurements in photon radiotherapy using polymer and Fricke MRI gel dosimetry'

To cite this article: Y De Deene *et al* 2003 *Phys. Med. Biol.* **48** L15

INSTITUTE OF PHYSICS PUBLISHING PHYSICS IN MEDICINE AND BIOLOGY

Phys. Med. Biol. **48** (2003) L15–L18 www.iop.org/Journals/pb PII: S0031-9155(03)56356-4

LETTER TO THE EDITOR

Comment on 'A systematic review of the precision and accuracy of dose measurements in photon radiotherapy using polymer and Fricke MRI gel dosimetry'

Received 20 November 2002

The Editor,

Sir,

In the recent article by MacDougall *et al* (2002), further referred to as 'the topical review', it was the authors' intention to bring a systematic review of the precision and accuracy in gel dosimetry. As their findings are included in the shape of a topical review in *Physics in Medicine and Biology* it can be expected that the topical review will be used as a first opinion on gel dosimetry by many readers that are not very familiar with the field of gel dosimetry. Therefore it is very important that the picture on accuracy and precision provided in this paper is complete and correct. It is our opinion that this topical review from individuals not known for their specialization and expertise in gel dosimetry is far from complete and is misleading.

The article clearly considers a calibrated ionization chamber as gold standard. However, the authors should realize that ionization chambers are not beyond all suspicion with regard to dosimetry in brachytherapy, intensity-modulated radiotherapy (IMRT) and stereotactic radiosurgery. Dose gradients and dynamic dose delivery may induce electronic disequilibrium and partial volume irradiation effects in the chamber response. Other detectors may be more adequate, e.g. the diamond detector (Westermark *et al* 2000). Further, brachytherapy, IMRT and stereotactic radiosurgery are the areas in which gel dosimetry will potentially be the preferred form of dosimetry.

The authors use a definition of accuracy and precision as well as the so-called 'exclusion criteria' to exclude what they call 'papers of insufficient quality'. It is our opinion that although their definitions and exclusion criteria may be suitable for the evaluation of point detectors (ionization chambers, TLDs, diamond detectors) they are inadequate and inappropriate in the evaluation of precision and accuracy of three-dimensional integrating dosimeters such as gel dosimeters. Several efforts have been made and communicated by other researchers to develop more adequate ways to define figures of precision (Baldock *et al* 2001, De Deene *et al* 1998a, 2002a) and accuracy for gel dosimetry.

Another way to calculate the uncertainty of gel dosimeters (Fricke gels) was also proposed by Bäck *et al* (1998) and further discussed by Baldock *et al* (2001) and is based on recommendations from the International Organization for Standardization (ISO 1995). A methodology was developed to determine the uncertainty in measurement using two groups of uncertainties. Type A uncertainties are determined by statistical methods and type B uncertainties are contributions that cannot be determined by statistical methods. This is an alternative to using a more traditional grouping of 'random' (or 'precision') and 'systematic' (or 'biased') uncertainties (Coleman and Steele 1999).

With respect to precision in gel dosimetry we emphasize that care has to be taken in giving one specific figure. The final precision is determined by four factors: (1) chemical variations; (2) variations in the delivered dose; (3) variations that are related to scanning the gels; and (4) the dose response of the gel. For the evaluation of gel dosimeters using MRI, the induced variations are strongly dependent on imaging parameters (sequence type, field strength, field-of-view, averaging volume, measurement time, etc) of the image noise and of the imaging artefacts. For a treatment of factors that influence the precision related to scanning we refer to several papers by De Deene *et al*. Researchers have been careful in providing absolute values for precision and have developed more sophisticated ways to describe precision. The dose resolution (Baldock *et al* 2001) is an adequate and well accepted parameter that comprises the factors (3) and (4).

On page R111 of the topical review in the section entitled 'Variables', the authors state that there is insufficient evidence of precision to allow the investigation of the effect of different variables that affect the precision. Contrary to this and without going into detail it can be stated that a lot of the effects mentioned have been studied and reported in the literature.

Of much concern is that table 3 showing the polymer gel accuracy with relaxed exclusion criteria is incomplete. In the first paper mentioned in the table (De Deene *et al* 1998b) deviations in the order of 8% were found in the case of the IMRT treatment. However in that same paper, mention was also made of a comparison between gel dosimetry and ionization chamber and diamond detector measurements for a depth-dose curve and cross-beam profiles of an external beam. It was found that 'The root mean square difference between the dose profiles measured with the different methods remains within 3%'. The larger variations in the case of IMRT treatment (8%) were partially attributed to inhibition by oxygen on the walls of the recipient. Following this preliminary study in 1998 several studies have been performed in order to enhance the accuracy. Several sources of inaccuracy were discovered and compensation strategies have been developed. These sources and compensation methods have been discussed in several papers. The compensation strategies were then implemented in another 3D gel dosimetry experiment in which 18 dose maps obtained with gel dosimetry were compared with corresponding dose maps obtained with film and computer planning. We would like to emphasize that this study is quite unique in its kind as it compares dose distributions in a complete three-dimensional volume and not in one point or one slice. The corresponding averaged structural root-mean-square deviation taken as a figure of accuracy in this study amounted to 3% and 5% for comparisons with film and planning respectively (De Deene *et al* 1999, 2000). A distance-based approach to compare the dose maps of the different dosimetry modalities has also been discussed. It is most regrettable that these figures can not be found in table 3. By neglecting these figures the authors provide a most incorrect and misleading impression about the accuracy of gel dosimetry.

On page R114, the authors state that 'it can be hypothesized that the precision and accuracy may be improved in polymer and Fricke gels by increasing the gel sensitivity by ways as tabulated'. This is not the case as has recently been quantitatively proven by De Deene and Baldock (2002a). The references to the variables that influence the accuracy and precision are completely inadequate. The factors mentioned in the topical review should not be 'hypothesized' as possible sources of inaccuracy as it has been proven quantitatively to what extent they have an influence on precision and accuracy. Some examples follow. (1) The effect of different gel compositions has been studied extensively by Lepage *et al* (2001a). (2) Without criticizing the authors of the topical review on this specific point, we would like to mention that very recently a quantitative study was performed on the influence of time between irradiation and scanning on the change in dose response for normoxic gels (De Deene *et al* 2002b). (3) The authors of the topical review stated that there are no papers that report energy-dependency

of the gel dosimeters. This is in contradiction with a paper by Novotny *et al* (2001) were mention was made of a decrease in dose sensitivity as function of photon or electron energy. (4) With respect to the influence of the time from irradiation to scanning, the authors refer to a paper by McJury *et al* (1999). It should be mentioned that in the paper by McJury, changes in R2 are reported in the order of hundreds of per cent. This makes the referred to study very suspicious and not representative for most polymer gels. The chemical stability of gels was extensively studied and reported in several other studies (De Deene *et al* 2000, 2002, Lepage *et al* 2001b). Strategies and guidelines to compensate for these instabilities are provided in these publications. (5) The contradictory results reported by Haraldsson *et al* (2000) and Maryanski *et al* (1993) of the dependence of the dose response (R2) on MR field strength can be easily explained. Both authors did not make a comprehensive analysis, as not only the field strength was varied but different sequences were used as well. It is well known that the measured R2 value is dependent on the sequence type because of the contribution of stimulated echoes, the effect of eddy currents and diffusion weighting (De Deene *et al* 1999). (6) Regarding the linearity of the gel's radiation response it should be noted that the gel dosimeter is definitely non-linear. The higher the given dose, the more reactive monomers are consumed in the gel. A first-order differential equation describes this simplified model. The solution is a mono-exponential. It is not within the scope of this letter to discuss the shape of the dose–R2 plot in detail. It is our opinion that a bi-exponential course is a suitable description of the dose–R2 plot for the polymer gels that have been studied so far. Very often the exponential dose–R2 plot can be approximated by a linear fit within a certain dose range.

In the final sentence, on page R115, the authors conclude that 'the basic radiation dosimeter qualities of accuracy and precision have yet to be fully quantified at clinically relevant dose levels'. We disagree on this point as gel dosimeters are primarily used as relative dosimeters. They should not necessarily be used in a clinically-relevant dose range but in the dose range in which the dose resolution is optimal as is also the case with film dosimetry.

Minor points of error in the topical review include a typo on page R110 (line 9) as 'relation' should be 'relaxation', and a wrong reference on page R114 (2.4 (vii)) in which 'Maryanski *et al* (1994)' should be 'Maryanski *et al* (1993)'.

Y De Deene and C De Wagter
Department for Radiotherapy,
Ghent University Hospital,
Belgium
(E-mail: Yves.DeDeene@rug.ac.be)

C Baldock
Centre for Medical,
Health and Environmental Physics,
Queensland University of Technology,
Australia
(E-mail: c.baldock@qut.edu.au)

References

Bäck S A J, Magnusson P, Fransson A, Olsson L E, Montelius A, Holmberg O, Andreo P and Mattsson S 1998 Improvements in absorbed dose measurements for external radiation therapy using ferrous dosimeter gel and MR imaging (FeMRI) *Phys. Med. Biol.* **43** 261–76

Baldock C, Lepage M, Back S A J, Murry P J, Jayasekera P M, Porter D and Kron T 2001 Dose resolution in radiotherapy polymer gel dosimetry: effect of echo spacing in MRI pulse sequence *Phys. Med. Biol.* **46** 449–60

Coleman H W and Steele W G 1999 *Experimentation and Uncertainty Analysis for Engineers* (New York: Wiley)

De Deene Y, Van de Walle R, De Wagter C and Achten E 1998a Mathematical analysis and experimental investigation of noise in quantitative magnetic resonance applied in polyacrylamide gel dosimetry *Sign. Proc.* **70** 85–101

De Deene Y, De Wagter C, Van Duyse B, Derycke S, De Neve W and Achten E 1998b Three-dimensional dosimetry using polymer gel and magnetic resonance imaging applied to the verification of conformal radiation therapy in head-and-neck cancer *Radiother. Oncol.* **48** 283–91

De Deene Y and De Wagter C 1999 Gel dosimetry in conformal radiotherapy: Validation, optimization and MR artifacts *Proc. of the first International Workshop on Radiation Therapy Gel Dosimetry (Lexington, Kentucky)* 75–89

De Deene Y, De Wagter C, Van Duyse B, Derycke S, Mersseman B, De Gersem W, Voet T, Achten E and De Neve W 2000 Validation of MR-Based Polymer Gel Dosimetry as a Preclinical Three-Dimensional Verification Tool in Conformal Radiotherapy *Magn. Reson. Med.* **43** 116–25

De Deene Y and Baldock C 2002a Optimization of multiple spin-echo sequences for 3D polymer gel dosimetry *Phys. Med. Biol.* **47** 3117–41

De Deene Y, Hurley C, Venning A, Vergote K, Mather M, Healy B J and Baldock C 2002b A basic study of some normoxic polymer gel dosimeters *Phys. Med. Biol.* **47** 3441–63

De Deene Y, Venning A, Hurley C, Healy B J and Baldock C 2002c Dose-response stability and integrity of the dose distribution of various polymer gel dosimeters *Phys. Med. Biol.* **47** 2459–70

Haraldsson P, Back S A J, Magnusson P, and Olsson L E 2000 Dose response characteristics and basic dose distribution data for a polymerization-based dosemeter gel evaluated using MR *Br. J. Radiol.* **73** 58–65

ISO (International Organization for Standardization) 1995 *Guide to the Expression of Uncertainty in Measurement*

Lepage M, Jayasakera P M, Back S A J and Baldock C 2001a Dose resolution optimization of polymer gel dosimeters using different monomers *Phys. Med. Biol.* **46** 2665–80

Lepage M, Whittaker A K, Rintoul L, Back S A J and Baldock C 2001b Modelling of post-irradiation events in polymer gel dosimeters *Phys. Med. Biol.* **46** 2827–39

MacDougall N D, Pitchford W G and Smith M A 2002 A systematic review of the precision and accuracy of dose measurements in photon radiotherapy using polymer and Fricke MRI gel dosimetry *Phys. Med. Biol.* **47** R107–21

Maryanski M, Gore J C, Kennan R P and Schulz R J 1993 NMR relaxation enhancement in gels polymerized and cross-linked by ionizing radiation: A new approach to 3D dosimetry by MRI *Magn. Reson. Imaging* **11** 253–8

McJury M, Oldham M, Leach M O, Webb S 1999 Dynamics of polymerization in polyacrylamide gel (PAG) dosimeters: (I) ageing and long-term stability *Phys. Med. Biol.* **44** 1863–73

Novotny J Jr, Spevacek V, Dvorak P, Novotny J, Cechak T 2001 Energy and dose rate dependence of BANG-2-polymer-gel dosimeter *Med. Phys.* **28** 2379–86

Westermark M, Arndt J, Nilsson B and Brahme A 2000 Comparative dosimetry in narrow high-energy photon beams *Phys. Med. Biol.* **45** 685–702