Dosimetry in HDR brachytherapy with Fricke-gel layers and Fricke-gel catheters

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Abstract. Fricke-gel layer dosimeters (FGLD) and Fricke gel dosimetric catheters (FGDC) have been designed and tested with the aim of enquiring their suitability for HDR \textsuperscript{192}Ir brachytherapy source control and for in-vivo dose verification during treatment. Anisotropy function measurements have been carried out with FGLDs in which a thin plastic tube has been placed in for the \textsuperscript{192}Ir source insertion. FGDCs are constituted by plastic tubes (3 mm of external diameter and 13 cm of length) filled with the dosimeter-gel. Absorbed dose images and profiles were attained by means of optical analysis. Dedicated software has been developed both for achieving anisotropy function values and for obtaining reliable results in visible light absorbance measurements across the thin cylindrical dosimeters. Preparation and analysis procedures have been optimised. The results confirm that the proposed methods are very promising for HDR brachytherapy dosimetry.

1. Introduction

HDR \textsuperscript{192}Ir brachytherapy is a radiotherapy modality achieving more and more important role for cancer treatment. AAPM Task Group 43 \cite{1,2} has outlined a protocol for dose to water calculation based on the results of air-kerma strength measurements. Conspicuous experimental activities have been carried out for dosimetry measurements in HDR \textsuperscript{192}Ir brachytherapy, in particular in water phantoms \cite{3,4}, also utilising Fricke-gel \cite{5-7}.

Some Fricke-gel layer dosimeters (FGLD) were prepared containing a catheter to be jointed to the \textsuperscript{192}Ir source applicator. In such a way, the brachytherapy source can enter into the gel dosimeter. This dosimeter can be placed in a water-equivalent phantom for 2-D dose measurements or piled up with FGLDs having the same size but without catheter, for 3-D measurements \cite{8}. Each dosimeter can be previously properly calibrated, in order to achieve absolute dose results with good precision.

Besides in-phantom measurements, it is important to perform also reliable in-vivo dosimetry during HDR brachytherapy treatments, in order to verify the correctness of exposures. In particular, when the therapy is fractionated in more sessions, it is of particular importance to execute a check of the dose absorbed during each exposure. In-vivo dosimetry is particularly complex in HDR brachytherapy,
because the high gradients require high spatial resolution. At present, the chosen detectors are mostly TLDs or, if immediate readout is necessary, diodes and MOSFETs. Fricke gel dosimeter sealed in thin transparent catheters (FGDC) has shown to be a good candidate for in-vivo dosimetry during a HDR radiotherapy treatment. For reliable optical analysis of such thin cylindrical dosimeters, a suitable method was set up and tested. Feasibility measurements with HDR brachytherapy unit were performed to assess the reliability of FGDCs for in-vivo dosimetry during brachytherapy treatments.

2. Material and methods

The Fricke gel dosimeters that are at the basis of the methods are laboratory-made radiochromic gels; the composition is: Agarose in the amount of 3% of the final weight, ferrous sulphate solution [1mM Fe(NH$_4$)$_2$(SO$_4$)$_2$•6H$_2$O]; sulphuric acid [25 mM H$_2$SO$_4$] and xylene-orange [0.165 mM C$_{32}$H$_{27}$N$_2$Na$_5$O$_{13}$S].

For in-phantom measurements, FGLDs were prepared, consisting of gel contained between two transparent PMMA sheets, 1 mm thick. The gel thickness is of 3 mm and the frame around is usually squared, with side length of 12 cm. In some frames, a catheter for the introduction of the $^{192}$Ir source is sealed. In Figure 1, a dosimeter after irradiation aimed at measuring the anisotropy function is shown. If the dosimeters are properly calibrated, absolute dose measurements are realizable, with good precision [11].

For in-vivo measurements, FGDCs were produced utilizing transparent plastic tubes with an external diameter of 3 mm and a length of 13 cm.

The dosimeter reading is based on visible light absorbance. Dosimeters are positioned on a uniform planar source of light, inserted in a special frame fitting their shape, and the transmitted light is imaged before and after irradiation. Images are acquired using a CCD camera with a band-pass filter centred at 585 nm. The measured difference in optical density ($\Delta$(OD)) is proportional to the absorbed dose. The acquired images are analysed with the software suitably developed for each kind of dosimeter.

2.1. Dedicated software

The dedicated software (in MatLab® code) for FGLDs analysis has been suitably developed and improved [9,10], with the aim of getting better results by removing artefacts [11], effects of lack in thickness uniformity and so on.

The software for FGDCs is now in development. The dosimeter cylindrical shape implies that transmission of light occurs through a non-planar surface. Due to this feature, a special method to obtain a reliable correlation between image’s gray level and absorbed dose was developed. The software finds out the position of the catheter’s central axis for every row perpendicular to this axis, and then it evaluates the mean gray-level over 5 pixels centred on this position. In Figure 2, a sketch illustrating this procedure is shown. Finally, the software calculates the fitted lengthways profile of the $\Delta$(OD) for percentage depth dose (PDD) measurements or of the absorbed dose, if the FGDCs have been calibrated, for absolute dose measurements.

Proper software has been developed also to compensate effects of non-homogeneous response within the same FGLD or FGDC. This lack in homogeneity could be due to the non-uniformity of both the CCD camera and the planar light source and/or to the dosimeter non-homogeneous sensitivity. Light transmittance images acquired before and after dosimeter irradiation in a uniform field are processed by this software, attaining a correction image for FGLD, or a correction profile for FGDC. In such a way, pixel-to-pixel correction of the dosimeter response can be performed.

2.2. Dosimeter calibration

Mostly, the dosimeters have been preliminarily irradiated in an uniform photon field, at 4 Gy, for non-homogeneity correction purpose. Moreover, for absolute dose measurements, the dosimeters were
calibrated with the following procedure. Each dosimeter was exposed to a uniform photon beam, suitably surrounded by TE plastic, so to have a known uniform dose (4 Gy) absorbed in the gel dosimeter. Since Fricke gel dosimeter response is independent by dose rate and radiation energy, this irradiation was carried out with photons from a 6 MV clinical linear accelerator. The Δ(OD) image obtained, for each dosimeter, from the transmittance images acquired before and after such an irradiation, was utilised for attaining the dose-calibration image of the specific dosimeter. Such preliminary irradiations were always performed in the same day of the measurement. A study is in program to enquire the possibility of performing the dosimeter calibration one or two days before measurement.

2.3. Brachytherapy unit

All experiments were carried out at a Microselectron-HDR high dose rate unit, from Nucletron (Veenendaal, the Netherlands). The system is provided with a $^{192}\text{Ir}$ radioactive source and a remote afterloading device. The source has an active length of 3.6 mm and a diameter of 0.65 mm. The source is incapsulated at the end of a flexible cable and driven to the dwell positions evaluated by the treatment plane.

Figure 1 – FGLD with the inserted catheter for the introduction of $^{192}\text{Ir}$ source by remote control, after irradiation for anisotropy function measurement.

Figure 2 – Sketch of the central region of the thin cylindrical FGDC where the Δ(OD) is evaluated.

3. Results and discussion

A characterization of FGLDs irradiated at the brachytherapy source has been carried out, determining the linearity range and setting up the calibration procedure. The calibration method requires two exposures at 4 Gy. Then, the dosimeter response is linear in the range 0-20 Gy. The dosimeter response at irradiation temperature of 37°C (temperature of human body) was investigated, for preliminary test of the feasibility of in-vivo utilization of this dosimetric compound.

Some measurements were performed irradiating FGLDs with the $^{192}\text{Ir}$ source stopped at the center of the dosimeter for a convenient time. After having obtained the absorbed dose images, the
anisotropy function was evaluated by means of the properly developed software and the results were compared with the calculated values. The agreement is very good, within 3%, up to 30 mm of radial distance from the source. At higher distances the dispersion of data increases (remaining however within 5%), because the absorbed dose becomes very low. Some results are shown in Figure 3.

The new proposed catheters for in-vivo dosimetry (plastic tubes with inner and outer diameter of 4F and 6F, respectively) have been widely studied in order to (i) optimize the number of pixel utilized for determining the Δ(OD) all along the dosimeter, that is the dosimeter resolution, (ii) verify the linearity range, (iii) investigate the achievable precision for absolute dose measurements by means of previous calibration of each dosimeter and (iv) explore the feasibility of using thinner catheters, with external diameter of 2 mm.

FGDC measurements were also performed positioning many dosimeters in a water-equivalent phantom that was irradiated with the high dose rate remote afterloading device, with a complex treatment plane. The dosimeters were preventively calibrated following the adopted procedure, shortly described in Section 2.2 and in a previous work [13]. The results [14] show a very good consistency between measured and calculated dose profiles, showing the validity of the proposed method.

The improvement of the method aimed at using catheters with 2 mm of external diameter in now in progress. To this aim, better resolution of the optical analysis system (CCD camera plus uniform light source) is necessary. The new instrumentation is now in phase of setting up.

In conclusion, the proposed methods show to be promising for high dose rate brachytherapy dosimetry. Their characteristics suggest that such dosimeters could be proposed for clinical routine protocols.

Figure 3 – Results of anisotropy function measurement performed by means of a FGLD in which the $^{192}$Ir source was introduced through an inserted catheter.
References

[1] Nath, R., Anderson, L. L., Luxton, G., Weaver, K. A., Williamson, J. F. and Meigooni, A. S., 1995, Dosimetry of interstitial brachytherapy sources: Recommendations of the AAPM Radiation Therapy Committee Task Group No. 43. American Association of Physicists in Medicine, Med. Phys. 22, 209–234.

[2] Rivard, M. J., Coursey, B. M., DeWerd, L. A., Hanson, W. F., Huq, M. S., Ibbott, G. S., Mitch, M. G., Nath, R. and Williamson, J. F., 2004, Update of AAPM Task Group No. 43 Report: A revised AAPM protocol for brachytherapy dose calculations, Med. Phys. 31, 633–674.

[3] Sarfehnia, A. and Seuntjens, J., 2010, Development of a water calorimetry-based standard for absorbed dose to water in HDR 192Ir brachytherapy, Med. Phys. 37, 1914-1923.

[4] Sarfehnia, A., Kawrakow, I., Seuntjens, J., 2010, Direct measurement of absorbed dose to water in HDR 192Ir brachytherapy: Water calorimetry, ionization chamber, Gafchromic film, and TG-43. Med. Phys. 37, 1924-1932.

[5] Olsen, D. R. and Hellesnes, J., 1994, Absorbed dose distribution measurements in brachytherapy using ferrous sulphate gel and magnetic resonance imaging, Br. J. Radiol. 67, 1121–1126.

[6] Schreiner, L. J., Crooks, I., Evans, M. D., Keller, B. M. and Parker, W. A., 1994, Imaging of HDR brachytherapy dose distributions using NMR Fricke gelatin dosimetry, Magn. Reson. Imaging 12, 901–907.

[7] Austerlitz, C., Mota, H. C., Sempau, J., Benhabib, S. M., Campos, D., Allison, R., DeAlmeida, C. E., Zhu, D. and Sibata, C. H., 2008 Determination of absorbed dose in water at the reference point d(r0, theta0) for an 192Ir HDR brachytherapy source using a Fricke system, Med. Phys. 35, 5360–5365.

[8] Carrara, M., Fallai, C., Gambarini, G., Negri, A., 2010, Fricke gel-layer dosimetry in high dose-rate brachytherapy. Applied Radiation and Isotopes 68, 722–725.

[9] Carrara, M., Gambarini, G., Tomatis, S., 2005. Experimental imaging and 3D rendering of absorbed dose means of piled-up dosimetric sheets. IEEE Nuclear Science Symposium Conference Record (IEEE Cat. No.05CH37692C) : 870-873

[10] Gambarini, G., Carrara, M., Valente, M., 2006. 3D-Reconstruction of absorbed dose obtained from gel-dosimeter-layers. 9th ICATPP Conference on Astroparticle, Particle, Space Physics, Detectors and Medical Physics Applications, 705-709, ed. World Scientific (ISBN 981-256-798-4)

[11] Carrara, M., Gambarini, G., Tomatis, S., Valente, V., 2007. Dose distribution measurements by means of gel-layer dosimeters. Evaluation of algorithms for artifacts amendment. Nucl. Instr. Meth. A 580, 334-338

[12] Gambarini, G., Carrara, M., Gambini, I., Tomatis, S., Negri, A., Mariani, M., Fallai, C., Olmi, P., Zonca, G., Fricke gel layer dosimetry for in-phantom absolute dose measurements in HDR brachytherapy. Radiat. Oncol. 92, Supplement 1, (2009), S104-S105

[13] Carrara M., Gambarini G., Gambini I., Tomatis S., Fallai C., Olmi P., Zonca G., 2009, A Novel Continuous Dosimeter for In-Vivo Absolute Dose Measurements in High Dose Rate Brachytherapy. Int. Journ. of Radiation Oncology Biology Physics, 75, S577-S578, ISSN: 0360-3016

[14] Carrara, M., Gambarini, G., Borroni, M., Tomatis, S., Cerrotta, A., Fallai, C., Olmi P. and Zonca, G., 2010, Feasibility study of a dosimeter for in vivo measurements of the absolute dose delivered in high dose rate brachytherapy. Accepted for publication on Il Nuovo Cimento, DOI 10.1393/ncb/i2010-10878-2