Characterisation of TruView™: a new 3-D reusable radiochromic MethylThymolBlue based gel dosimeter for ionising radiations

J Colnot, C Huet and I Clairand
Institut de Radioprotection et de Sûreté Nucléaire (IRSN), Service de Dosimétrie Externe, Laboratoire de Dosimétrie des Rayonnements Ionisants, Fontenay-aux-Roses, France
E-mail: christelle.huet@irsn.fr

Abstract. TruView™ is a new water-equivalent reusable Fricke gel dosimeter based on MethylThymolBlue reactive dye. Details of the characterisation of the TruView™ MTB gel dosimeter by spectrophotometric measurements and of its reading with the Optical-CT Scanner Vista™ are described. In this study, the different parameters influencing TruView™ dose response have been studied and its performances have been compared to chamber and diodes measurements. This gel presents a linear response with dose up to 20 Gy, independent in the investigated range of photon beam energy and dose rate and also a good intra-batch uniformity. Ions diffusion into the matrix homogenizes the gel after a week, losing dosimetric information but allowing a new irradiation to be performed. However, auto-oxidation happens before and after irradiation, degrading the dosimeter response and stability. Storage and reading conditions affect the response as well.

1. Introduction
Cutting-edge radiotherapy techniques deliver customized treatment to patients using both intensity modulation and numerous small beams. Thus, they lead to complex dose distribution with high dose gradients. Accurate and spatially precise dosimeters are needed to verify the match between planned and delivered dose [1-5]. Gel dosimeters are promising technique as they can inform about the whole 3-D dose distribution in one irradiation and without conventional dosimeters issues (electron equilibrium defect, partial volume effect, high dose gradient) [6]. There exist two main types of gel dosimeters: polymer gels [7] and radiochromic ones, each presenting different advantages and limitations. Fricke gel dosimeters [8-10], which are radiochromic, are reference water-equivalent 3-D dosimeters. Ionising radiation induces inside them the Fe²⁺/Fe³⁺ oxidation defining the irradiation print by a different light absorption [11]. The gel matrix retains ions after irradiation enabling stable spatial information. Optical-CT scanning is known to be the best technique to read this kind of gel combining fast scanning, great spatial resolution and important dynamic range for a low cost compared to MRI, x-ray, laser tomography and ultrasound [12-14]. The TruView™ MTB gel composition, manufactured by Modus Medical Devices Inc., is based on Fricke-MTB composition [15]: water (95%), low diffusive gelatin matrix (5%), sulfuric acid and ferrous ammonium sulfate, methylthymol blue reactive dye generating the color change, and stabilizing additives. This gel needs to be packed in jars and retains structural stability up to 25°C. Low diffusive structure facilitates Optical-CT readout avoiding scatter artifacts. The TruView™ gel presents new characteristics such as a new reactive dye and reusable structure. Dosimetric properties of this gel such as dose response, energy and dose rate dependency have been
studied by means of spectrophotometric measurements. Moreover, the influencing parameters during the different steps (container change, storage, irradiation and reading) have been identified and their impact has been studied. Finally, percent depth dose (PDD) as well as dose profiles of a 6 MV 1x1 cm² field size have been obtained using the Optical-CT Scanner Vista™ and compared to chamber and diodes measurements.

2. Materials and Methods

2.1. Dose response and uniformity of the TruView™ gel
Gel was packed in 1 cm square spectrophotometer polymethyl metacrylate cuvettes. Gel cuvettes were positioned at field isocenter of a 30 cm × 30 cm 4 MV photon beam with a 2.7 Gy/min dose rate delivered by an Elekta Synergy linear accelerator. Cuvettes were irradiated to doses from 0.25 Gy to 2 Gy in dose increments of 0.25 Gy and from 2 Gy to 20 Gy in dose increments of 2 Gy (one cuvette per dose). Low dose sensitivity was evaluated by irradiating 4 cuvettes per dose from 0.05 Gy to 0.3 Gy in dose increments of 0.05 Gy and at 0.5 Gy. Radiation induced changes in absorbance were measured using an UV1800 (Shimadzu) spectrophotometer 90 minutes after irradiation. Intra-batch uniformity was tested on 20 cuvettes (5 x 4 cuvettes irradiated simultaneously) stored and irradiated in the exact same conditions (10 Gy, 4 MV, 2.7 Gy/min).

2.2. Dose response as a function of energy and dose rate
To evaluate the influence of photon energy, gel dose response from 2 Gy to 20 Gy was performed for 3 energies (4, 10 and 18 MV) with a fixed dose rate (approximately 2.7 Gy/min). Absorbance change was measured two days after irradiation. Dose rate dependency was studied for 3 different dose rates (1.26 Gy/min, 2.56 Gy/min, 5.02 Gy/min).

2.3. Influence of different parameters on response
Regarding container change, storage, irradiation and reading steps, several parameters can influence gel dose response. For each step, error sources have been identified and quantified. Only the most significant ones are presented here. For gel container change, 10 Gy dose response of a Modus manufactured cuvette was compared to same age gel cuvettes home-conditioned using different preparation techniques: 35°C water bath heating, 50°C and 70°C hot-plate heating. Regarding the storage, to point out gel auto-oxidation, absorbance difference between two cuvettes filled under similar conditions with two gels of different aging (2 months and 1 week after manufacturing and 2 weeks) was measured. Dose response evolution up to 1 month after irradiation was studied using two different storages between readings (at room temperature and in refrigerator). Concerning the irradiation step, gel temperature influence was evaluated irradiating at 0.25 Gy and 2 Gy 4 cuvettes at room temperature and 4 others just got out of the refrigerator. About the reading step, influence of time between irradiation and reading was studied reading cuvettes at different time after irradiation and letting them at room temperature between readings.

2.4. Relative dosimetry
A 400 mL TruView™ jar was irradiated vertically in between PMMA slabs with a 1 cm × 1 cm field (4 MV, 3 Gy/min, 10 Gy at isocenter). Gel phantoms were scanned using the Vista™ Optical-CT, at 632 nm with 410 projections, 90 minutes after irradiation, the day after and 6 days after. Reconstructions were made in high resolution. 3-D reconstructions were analyzed using the MicroView 2.1.2 (GE Healthcare, UK) software. PDD and cross profiles were compared to PTW 31014 PinPoint chamber, PTW 60016 and 60017 diodes measurements.

3. Results

3.1. Dose response and uniformity of the TruView™ gel
In Figure 1, TruView™ dose response is represented as gel attenuation coefficient $\mu$ (cm$^{-1}$) as a function of dose. Gel response with dose is linear from 0.05 Gy up to 20 Gy, this batch sensitivity is around 0.0811 Gy$^{-1}$.cm$^{-1}$ at 632 nm (wavelength of maximum sensitivity). A good uniformity has been found: 3.56% relative discrepancy between 10 Gy dose response of a same batch.

![Figure 1. TruView™ dose response and spectral dose response on the 0.05 Gy-20 Gy dose range.](image1)

3.2. Dose response as a function of energy and dose rate
In the investigated energy range, dose response is independent of photon beam energy (Figure 2). Moreover, in this study, no observable dose rate dependence was detected (Figure 3).

![Figure 2. TruView™ dose response for 3 different energies.](image2)

![Figure 3. TruView™ dose response for 3 different dose rates (18 MV).](image3)

3.3. Influence of different parameters on response
Relative discrepancy between irradiated (10 Gy) Modus manufactured gel cuvettes compared to gel cuvettes made with 35°C water bath heating absorbances is of 2.86% and of 41.5% when compared with 50°C hot-plate heated cuvette. Two gels with different aging (2 months apart) have an absorbance difference of about 0.696 for 448 nm. For 20 Gy, after irradiation, the TruView™ absorbance decreases of 19.02% in 21 days when stored in refrigerator while, it decreases of 23.35% in 5 days when stored at room temperature. Gels irradiated at low temperature are less sensitive than those irradiated at room temperature: 27% of relative discrepancy between responses under 632 nm for 2 Gy and 5% for 0.25 Gy. After irradiation, gel response proves to be stable after 90 minutes.

3.4. Relative dosimetry
In 6 days, maximum dose on cross profiles decreases of 76.9% whereas attenuation coefficient increases in gel non-irradiated areas. A maximum discrepancy of 9.42% and 12% was found between PTW 60016 diode and gel PDD (Figure 4) and cross profiles FWHM respectively (Figure 5). FWHM values obtained
for inplane profiles were 8.89 mm, 8.74 mm, 8.75 mm and 9.80 mm for the chamber, the 60017 diode, the 60016 diode and the gel respectively.

Figure 4. Comparison between PDD obtained with the TruView™ gel and with the active detectors.

Figure 5. Comparison between gel and diode cross profiles.

4. Discussion

Linear dose response enables convenient calibration for relative dosimetry. Besides, gel independency with energy makes TruView™ an interesting candidate for radiotherapy verification. The dose rate independency study needs to be completed for higher dose rates, but TruView™ seems to be promising. However, this gel is sensitive to numerous packaging, irradiation and reading parameters so it needs to be carefully used to get accurate results. Dose was underestimated in the centre of the jar compared to detectors responses, this might be due to matching errors between profiles and stray light artifacts in the Vista™ system [16]. Then, differences in cross profiles FWHM can be explained by post irradiation ions diffusion inside the gel starting before 90 minutes.

5. Conclusion

3D, accurate and efficient dosimeters are needed to improve quality check in radiotherapy. Recently a new 3D radiochromic gel dosimeter was introduced; it is based on the Fricke dosimeter system with methylthymol blue dye in a gelatin matrix. This new gel presents comparable spectral properties with Fricke gels. It also exhibits great linearity with dose from 0 to 20 Gy, energy and dose rate independency (on the studied ranges). But further studies are required to benchmark this gel for clinical dose verification. In future research, the dose rate dependency will be studied over a larger range of dose rates. Absolute dose comparison is also currently ongoing. Finally, another study to find out how reuse impacts on accuracy and precision is ongoing.

6. Acknowledgements

We thank Jennifer Dietrich and Kalin Penev of Modus Medical Devices Inc. for assistance with gel supply and helpful discussions regarding Vista™ properties.

7. References

[1] Hill R et al 2014 Phys. Med. Biol. 59 R183-231
[2] Vial P et al 2008 Med. Phys. 35 1267-77
[3] Greer P B et al 2007 Med. Phys. 34 4389-98
[4] Mather M L et al 2003 Ultrasonics 41 551-9
[5] Hill B et al 2005 Med. Phys. 32 1589-97
[6] Babic S et al 2008 Int. J. Radiat. Oncol. Biol. Phys. 70 1281-91
[7] Chiu C Y et al 2014 Appl. Radiat. Isoto. 90 245-250
[8] Gun F et al 2002 Phys. Med. Biol. 47 67-77
[9] Fricke H and Morse S 1927 Am. J Roent. Radium Ther. Nucl. Med 18 430-2
[10] Gore J C et al 1984 Phys. Med. Biol. 29 1189-97
[11] Davies J B and Baldock C 2008 Radiat. Phys. Chem. 77 690-6
[12] Baldock C et al 2010 Phys. Med. Biol. 55 R1-63
[13] Oldham M et al 2001 Med. Phys. 28 1436-46
[14] Schreiner J L 2004 J. Phys.: Conf. Ser. 3 9-21
[15] Penev K I and Mequanint K 2015 J. of Phys.: Conf. Ser. 573 012030
[16] Olding T et al 2010 Phys. Med. Biol. 55 2819-40