Radiation Physics and Chemistry 104 (2014) 283–286

Contents lists available at ScienceDirect

Radiation Physics and Chemistry

journal homepage: www.elsevier.com/locate/radphyschem

Characteristics of polyacrylamide gel with THPC and Turnbull Blue gel dosimeters evaluated using optical tomography

Kateřina Pilařová (Vávrů) [a,*], Petra Kozubíková [a], Jaroslav Šolc [b], Václav Spěváček [a]

[a] *Czech Technical University in Prague, Faculty of Nuclear Sciences and Physical Engineering, Břehová 7, 11519 Prague, Czech Republic*
[b] *Czech Metrology Institute, Inspectorate for Ionizing Radiation, Radiová 1, 10200 Prague, Czech Republic*

HIGHLIGHTS

• Gel dosimeters are suitable for steep dose gradient verification.
• An optical tomography evaluation method is successful.
• Dose response characteristics of TB gel and PAGAT gel are presented.

ARTICLE INFO

Article history:
Received 11 July 2013
Accepted 18 May 2014
Available online 24 May 2014

Keywords:
Gel dosimetry
Optical tomography
Turnbull Blue gel dosimeter
PAGAT dosimeter

ABSTRACT

The purpose of this study was to compare characteristics of radiochromic gel – Turnbull Blue gel (TB gel) with polymer gel – polyacrylamide gel and tetrakis hydroxymethyl phosphonium chloride (PAGAT) using optical tomography. Both types of gels were examined in terms of dose sensitivity, dose response linearity and background value of spectrophotometric absorbance.

The calibration curve was obtained for ^{60}Co irradiation performed on Gammacell 220 at predefined gamma dose levels between 0 and 140 Gy for TBG and 0–15 Gy for PAGAT. To measure relative dose distributions from stereotactic irradiation, dosimeters were irradiated on Leksell Gamma Knife Perfexion. The cylindrical glass housings filled with gel were attached to the stereotactic frame. They were exposed with single shot and 16 mm collimator by 65 Gy to a 50% prescription isodose for TB gel and 4 Gy to a 50% prescription isodose for PAGAT. Evaluations of dosimeters were performed on an UV–vis Spectrophotometer Helios β and an optical cone beam homemade tomography scanner with a 16-bit astronomy CCD camera with a set of color filters.

The advantages and potential disadvantages for both types of gel dosimeters were summarized. Dose distribution in central slice and measured profiles of 16 mm shot shows excellent correspondence with treatment planning system Leksell GammaPlan® for both PAGAT and Turnbull Blue gels.

1. Introduction

Stereotactic radiosurgery with a Leksell gamma knife is a conformal technique for intracranial irradiation. Because of the steep dose gradient, target volume obtain sufficient dose while organs at risk are well spared and therefore treatment is usually performed in one session. Verification of such a complex dose distribution with conventional approach is difficult and gel dosimeters are promising technology (Baldock et al., 2010). For the evaluation of gel dosimeters optical tomography became the widely used method. The optical scanner was developed as an effective alternative to MRI (Gore et al., 1996) and allows evaluating radiochromic (Doran et al., 2001) as well as polymer (Sarabipour et al., 2007) gel dosimeters.

The purpose of this study was to compare dosimetric characteristics of radiochromic gel – Turnbull Blue gel (TB gel) with polymer gel – polyacrylamide gel and tetrakis hydroxymethyl phosphonium chloride (PAGAT) using optical tomography. This method relies on the attenuation of light by the gel, which changes as a function of the absorbed dose.

A polymer gel dosimeter is composed of monomers distributed in a gel matrix. Radiation induced polymerization of the monomers and subsequent chain propagation produce a rigid polymer within the gel. Light scattering on the polymer is the primary mechanism of optical contrast and is proportional to absorbed dose.

The dosimeter based on Turnbull blue dye – TB gel is composed of a gel matrix, potassium ferricyanide and ferric compound dissolved in an acidic medium. During irradiation ferric ions (Fe^{3+}) are reduced to

* Corresponding author. Tel.: +420 224 358 239.
E-mail address: katerina.vavru@fjfi.cvut.cz (K. Pilařová (Vávrů).)

http://dx.doi.org/10.1016/j.radphyschem.2014.05.039
0969-806X/

ferrous ions (Fe^{2+}) and the insoluble dye Turnbull blue $K[Fe^{II}Fe^{III}(CN)_6]$ is formed. Turnbull blue has wide absorption peak with a maximum at wavelength of approximately 690 nm and the change in light absorption is proportional to absorbed dose. The main advantage of this radiochromic gel is the linearity of the dose response up to 400 Gy and inhibited diffusion (Šolc and Spěváček, 2009).

2. Materials and methods

2.1. Gel preparation

A TB gel and PAGAT gel were prepared according to preparation procedure suggested by Šolc and Spěváček (2009) and Vávrů et al. (2013). Details of chemical compositions of gel dosimeters are summarized in Table 1. Prepared gels were poured into polymethyl methacrylate spectrophotometric cuvettes with internal dimension $1 \times 1 \times 4.5\ cm^3$ and into glass cylindrical housing (10 cm diameter, 9 cm height). Both gel samples and large volume were stored in a refrigerator at 5 °C. PAGAT gel and TB gel in cuvettes solidified within 24 h. Solidification of TB gel in the large volume took about 72 h.

2.2. Irradiation

Calibration cuvettes were irradiated using ^{60}Co irradiator GammaCell 220 with dose rate of 55.8 Gy/h. Samples of TB gel were irradiated up to 140 Gy with 10 Gy steps 48 h after manufacturing. PAGAT calibration cuvettes were irradiated by 1 Gy step in a range of 1–15 Gy 19 h after manufacturing.

Irradiation of large cylindrical volume was performed using Leksell Gama Knife unit Perfexion™ (Electa, Stockholm) with the dose rate of 2.456 Gy/min at the date of irradiation. For this purpose a special holder was developed. This holder enables to attach the cylindrical glass housing to the Leksell Stereotactic Frame with four titanium screws. The phantom was irradiated with one 16 mm shot placed in the isocentre to a prescription dose of 65 Gy to 50% isodose for TB gel and 4 Gy to 50% isodose for PAGAT gel. For planning Leksell GammaPlan (LGP) treatment planning software, Version 10.1 (Elekta AB, Stockholm, Sweden), uses a cubic matrix of $31 \times 31 \times 31$ grid points with variable grid spacing.

2.3. Absorbance measurement

Absorbance change measurements were performed using the UV–vis Spectrophotometer Helios β on wavelength of 690 nm and 680 nm for TB and PAGAT gel respectively. To investigate the stability of dosimeters response in time, the absorption of each cuvette was measured at different time intervals after irradiation. Dose response curves are summarized in Figs. 1 and 2. All cuvettes were kept in cold (5 °C) and dark environment.

Table 1
Chemical compositions of TB and PAGAT gel dosimeters.

Dosimeter based on Turnbull blue dye (TB gel)	
Agarose (phytagel)	0.5% w/w
Potassium ferricyanide ($K_3Fe(CN)_6$)	0.5 mM
Ferric chloride ($FeCl_3$)	0.5 mM
Sulfuric acid (H_2SO_4)	1 mM
Polyacrylamide gel and THPC (PAGAT gel)	
Gelatin (from porcine skin, Type A)	5% w/w
Acrylamide (C_3H_5NO)	3% w/w
N,N′-methylenebisacrylamide ($C_7H_{10}N_2O_2$)	3% w/w
Tetrakis (hydroxymethyl) phosphonium chloride (THPC)	10 mM

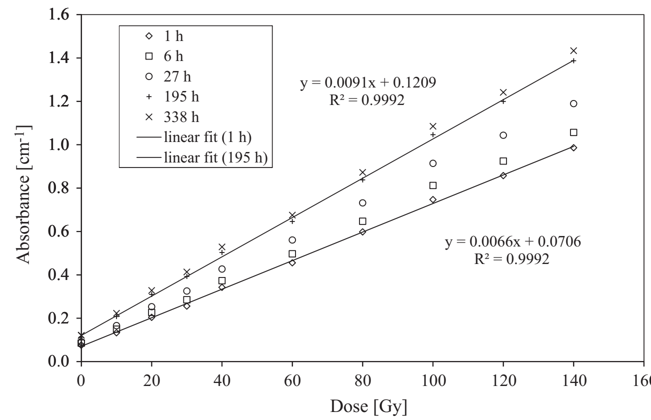

Fig. 1. TB gel dose response curve measured on 690 nm by an absorption spectrophotometer.

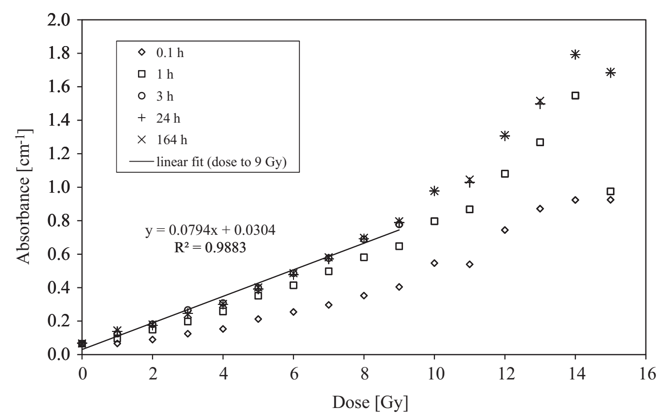

Fig. 2. PAGAT gel dose response curve measured on 680 nm by the absorption spectrophotometer.

2.4. Optical CT scanning

The glass cylindrical volume was scanned using homemade optical CT scanner – 16-bit astronomy CCD camera (G2-0402 type, Moravian Instruments, Czech Republic), stepper motor (65535 micro-steps per one 360° turn), light source (a yellow diode array HB5-434FY-C, Huey Jann Electronic, emitting light at a peak wavelength of 590 nm used for TB gel and a white diode array DataLight LT-81-W, Moravian Instruments with spectral filter of transmission maximum at 676 nm with FWHM 34 nm used for PAGAT gel). Data analysis was performed with in-house code developed in Matlab® suggested by Šolc and Spěváček (2009). The reconstructed image had resolution of 4.5 px/mm.

3. Results

Dose response relations of TB gel and PAGAT gel are summarized in Figs. 1 and 2 respectively. All samples were stored in dark at temperature of 5 °C. TB gel sensitivity, given by the slope of the linear fit, changed from $(66 \pm 0.7) \times 10^{-4}\ Gy^{-1}$ one hour after preparation to $(91 \pm 0.9) \times 10^{-4}\ Gy^{-1}$ 195 h after preparation. The background value increased from 0.071 to 0.12 cm^{-1} measured 1 h and 195 h after preparation respectively. The TB gel exhibited lower dose sensitivity and a wider linear dose response range, compared to PAGAT gel, where dose response was linear only up to 9 Gy. For PAGAT gel no significant ageing after 3 h from irradiation was found. PAGAT gel response was stable in time with measured