Radiation Physics and Chemistry 104 (2014) 40–44

Contents lists available at ScienceDirect

Radiation Physics and Chemistry

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

Effects of composition interactions on the response of a turnbull blue radiochromic gel dosimeter

Jiunn-I Shieh [a], Kai-Yuan Cheng [b], Huey-Lih Shyu [c], Yi-Chen Yu [b], Ling-Ling Hsieh [b,*]

[a] Department of Applied Informatics and Multimedia, Asia University, No. 500 Lioufeng Road, Wufeng, Taichung 413, Taiwan
[b] Department of Medical Imaging and Radiological Sciences, Central Taiwan University of Science and Technology, Taichung, Taiwan
[c] Department of Medical Laboratory Science and Biotechnology, Central Taiwan University of Science and Technology, Taichung, Taiwan

HIGHLIGHTS

- Analysis of the composition that influence TBG dosimeters via the design of experiments.
- Cross interactions between factors in the TBG dosimeters through multi-factor ANOVA.
- Two two-way interactions and one three-way interaction in the TBG dosimeters are significant.

ARTICLE INFO

Article history:
Received 4 June 2013
Accepted 1 March 2014
Available online 12 March 2014

Keywords:
Taguchi method
Turnbull blue
Radiochromic gel

ABSTRACT

In this study, the Taguchi statistical method was used to design experiments for investigating the effects of interactions among compositions on the performance of a Turnbull blue gel (TBG) radiochromic dosimeter. Four parameters were considered as the design factors: (A) concentration of ferric chloride, (B) concentration of potassium ferricyanide, (C) concentration of sulfuric acid, and (D) amount of gelling agent added. Two levels were selected for each factor. The change in optical absorbance at 695 nm under UVA exposures was monitored to determine the response of the dosimeters. The results showed that the contributions of factors A–D on the absorbance were 20.01%, 23.16%, 27.03%, and 0.49%, respectively. The contributions of significant interaction effects were AC (8.60%), BC (5.61%), and ABC (10.56%). This finding indicated that sulfuric acid (C) was the most influential factor, whereas gelling agent (D) was the least influential factor. Sulfuric acid had an important function in two two-way interactions and one three-way interaction in the response of TBG to UV exposure.

1. Introduction

Ultraviolet radiation (UVR) is the section of the electromagnetic spectrum that lies between X-rays and visible light. Human exposure to UVR is mainly due to the sun, which is the most important light source on earth. Solar UVR mainly comprises of UVC (100–280 nm), UVB (280–315 nm), and UVA (315–400 nm). However, almost all UVC and a large part of the UVB spectrum are absorbed by the ozone and other atmospheric gases. On the other hand, almost all solar UVA pass through the atmosphere and reach the surface of the earth. The damaging effects and the premature photoaging of human skin because of cumulative exposure to long UVA wavelengths (320–400 nm) have been reported (Bissett et al., 1992; Lavker et al., 1995). A predominance of UVA mutations in the basal cell layer of the human skin has also been reported (Agar et al., 2004). Thus, UVA has been classified as a potential carcinogen to the human skin, since it can penetrates the human skin at considerable depths.

Gel dosimeters was developed and used for measuring three-dimensional dose distribution for radiation (Bero et al., 2000). The gel itself absorbs UV radiation to a much greater extent when compared with water (Su and Yeh, 1996; Diffey, 1999). A new radiochromic gel based on the radiation-induced creation of the Turnbull blue dye (Turnbull blue gel [TBG] dosimeter) was developed and used to measure the spatial dose distribution in radiotherapy (Šolc et al., 2010). The gel itself has good sensitivity to UVR, and the effects of UVA radiation exposure can be quantitatively measured using a standard spectrophotometer. This study examined the quantitative contribution of each composition and its effects on the characteristics of TBG dosimeter by using the Taguchi method. The effects of the chemical interactions of the composition on the response of the dosimeter during photoreaction were also discussed.

* Corresponding author. Tel.: +886 422391647x7116; fax: +886 422396762.
E-mail address: llhsieh2013@gmail.com (L.-L. Hsieh).

http://dx.doi.org/10.1016/j.radphyschem.2014.03.003
0969-806X

2. Materials and methods

2.1. Preparation of the TBG dosimeters

The components of TBG include ferric chloride (98%, Alfa Aesar), potassium ferricyanide (99%, Sigma-Aldrich), diluted sulfuric acid (98%, Sigma-Aldrich), and gelling agent. Agarose (Agarose ME, Alfa Aesar), which was used as the gelling agent, was dissolved in deionized water (0.08% or 0.25% w/mL agarose) and placed into an 80 °C water bath. The solution became clear and transparent. Ferric chloride (1 mM or 20 mM) was dissolved in the diluted sulfuric acid. Before gel mixing, this solution was cooled to 35 °C. Ferric chloride was added into the solution by continuous stirring. Subsequently, potassium ferricyanide solution (1 mM or 40 mM) was added to the mixture. Gel samples were placed in cuvettes after TBG was mixed. Finally, the gel samples were wrapped in aluminum foil and stored in a refrigerator at 4 °C to prevent light-induced pre-photoreaction.

2.2. UV irradiation and optical spectroscopic measurements of the TBG dosimeters

The UV irradiation of the TBG samples were measured using a UVA (λ_{max} emission = 365 nm) lamp, which comprises three fluorescence tubes (Philips Actinic BL 8W). The UV intensities (unit: mW cm^{-2}) were measured using a UVX-36 radiometer (UVP, CA, USA). The UV/vis absorption spectra were obtained using a ChromTech CT-8600 UV/Vis spectrophotometer (Chrom Tech, Inc., Singapore).

2.3. Orthogonal array and experimental factors based on the Taguchi method

In this study, four parameters were considered as design factors, namely, (A) ferric chloride concentration, (B) potassium ferricyanide concentration, (C) sulfuric acid concentration, and (D) amount of agarose. Two levels were selected for each factor, as shown in Table 1. We conducted an experiment with an L16 (2^{15}) orthogonal array (16 tests, four variables, and two levels). The experiment design is shown in Table 2, and the variation in the absorbance at λ_{max} was assessed.

In the Taguchi method, the terms 'signal' (S) and 'noise' (N) represent the desirable and undesirable values for the output characteristics, respectively. The Taguchi method involves the use of the S/N ratio to measure the quality of the characteristic that deviates from the desired value. The S/N ratios differ according to the type of characteristic. Characteristic, and in case where high values are desired, the S/N ratio (η) is defined as (Roy, 1995)

$$\eta = -10 \log \left(\frac{1}{n} \sum_{i=1}^{n} \left(\frac{1}{x_i} \right)^2 \right), \tag{1}$$

where x_i is the measured data for the performance objectives and n is the number of measurements. In this study, $n = 3$ was used for all experiments.

3. Results and discussion

3.1. Optical characteristics of TBG dosimeters

When the TBG dosimeters were exposed to UVA irradiation, the unirradiated gel transforms gradually from transparent yellow to green and blue, due to the radiation-induced creation of the insoluble Turnbull blue dye. The spectrophotometric measurements of the TBG dosimeters were also recorded as a function of

Table 1
Design factors and their levels

Factor	Levels	
	1	2
$[FeCl_3]$ (mM)	0.06	1.23
$K[Fe(III)(CN)_6]$(mM)	0.03	1.21
$[H_2SO_4]$ (mM)	1	100
Agrose (%)	0.08	0.25

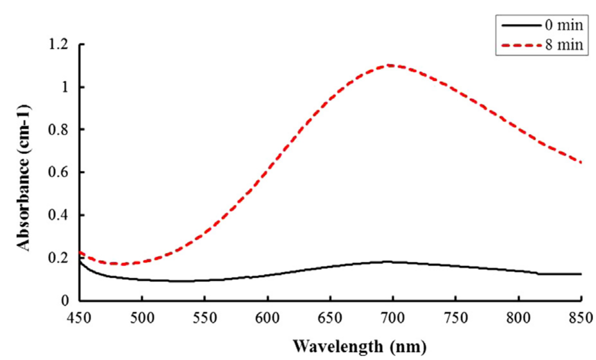

Fig. 1. UV/visible absorption spectra of unirradiated and irradiated TBG dosimeters.

Table 2
Layout of the L16 (2^{15}) orthogonal array.

Experiment number	Design factor														
	A	B	AB	C	AC	BC	ABC	D	AD	BD	ABD	CD	ACD	BCD	ABCD
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2
3	1	1	1	2	2	2	2	1	1	1	1	2	2	2	2
4	1	1	1	2	2	2	2	2	2	2	2	1	1	1	1
5	1	2	2	1	1	2	2	1	1	2	2	1	1	2	2
6	1	2	2	1	1	2	2	2	2	1	1	2	2	1	1
7	1	2	2	2	2	1	1	1	1	2	2	2	2	1	1
8	1	2	2	2	2	1	1	2	2	1	1	1	1	2	2
9	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
10	2	1	2	1	2	1	2	2	1	2	1	2	1	2	1
11	2	1	2	2	1	2	1	1	2	1	2	2	1	2	1
12	2	1	2	2	1	2	1	2	1	2	1	1	2	1	2
13	2	2	1	1	2	2	1	1	2	2	1	1	2	2	1
14	2	2	1	1	2	2	1	2	1	1	2	2	1	1	2
15	2	2	1	2	1	1	2	1	2	2	1	2	1	1	2
16	2	2	1	2	1	1	2	2	1	1	2	1	2	2	1