Gafchromic film as a fast visual indicator of radiation exposure of first responders at a radiological or nuclear accident

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The authors have studied the feasibility of Gafchromic films as visually readable dosimeters for first responders in connection with radiological or nuclear emergencies. Three types of Gafchromic films (XRQA, XRQA2 and RTQA2) were studied and the two most sensitive film types (XRQA and XRQA2) show a pronounced variation in sensitivity by photon energy and are therefore not suitable for use in cases of unknown exposures. The third film type tested (RTQA2), has a sensitivity that is independent of the radiation quality, and is therefore considered as the most optimal for visual reading *in-situ*. Tests carried out on a group of ten human observers showed that absorbed doses down to 35 mGy can be detected by the eye. Read by a portable densitometer, qualitative absorbed dose estimates down to 9 mGy can be achieved. The color change is obtained instantaneously, giving first responders immediate information about the presence of β-, γ- and X-ray radiation.

Gafchromic film, dose response, energy dependence, visual readout

INTRODUCTION

In an event of a radiation accident there is a need for the first responders to monitor their radiation exposure instantly. It is of interest to find a dosemeter that can be used across a wide range of radiation qualities. The dosemeter must be light in weight, portable, easy to use with minimal training, and affordable. An instantaneous reading of exposure in the appropriate dose range is desirable, so that timely and appropriate action can be taken regarding the rescue operation and preventing overexposure. Radiation dosemeters, such as pocket ionization chambers, Geiger-Muller counters, thermoluminesent dosimeters and other survey meters are either expensive, exhibit time delays between exposure and read-out, require regular charging of batteries and training for use. Radiochromic film has been found to be useful for monitoring radiation dose for emergency responders (Riel K Gordon, 2006). Gafchromic film (ISP, International Specialty Products, Wayne, NJ, USA), is widely used for radiation dosimetry in conventional radiotherapy and diagnostic radiology (Butson, 2003). The Gafchromic films develop automatically due to radiation-induced polymerization reactions within its sensitive layer. Upon irradiation, the Gafchromic film changes color from yellow to brown and the color intensifies as the absorbed dose increases, thereby providing the user information on cumulative radiation exposure. The change in optical density can be measured with densitometers, film scanners, or spectrophotometers (Devic, 2004). The aim of this investigation is to study the feasibility of Gafchromic film as a potential personal dosimeter, giving a *visual* qualitative measurement of exposure for first responders.

MATERIAL AND METHODS

Three different types of Gafchromic films were initially studied in these investigations. The RTQA2 film was specifically designed for use in radiation therapy quality assurance procedures. According to the manufacturer, the film is designed to be used in the absorbed dose range from 0.02 to 8 Gy. The films XRQA (dose range 2 - 500 mGy) and XRQA2 (1 – 200 mGy), were designed for use at clinical diagnostic x-ray energies. All three types of film have a white backing material and a yellow colored transparent polyester cover on the front, where the active layer is sandwiched between these two. They are constructed in this way to increase the visual color change seen upon exposure. Information regarding the film constructions and characteristics is available on the web site of the manufacturer (ISP). There are varying amounts of high atomic number dopants in Gafchromic products, thus creating a variable sensitivity for different radiation qualities, which may not be optimal for a mass scale application to rescue workers, who may be subject to photon exposures of unknown energy composition.

To evaluate the energy dependence of the dose response, irradiations were performed using an x-ray unit (A-196, Varian Medical Systems, USA), which operates at 80 kV and a ^{60}Co-unit (Gammatron-3, Siemens, Germany), with primary photon energies of 1.17 and 1.33 MeV. Irradiations were also performed with high-energy β-particles using a sealed ^{90}Sr/^{90}Y source (E_{Max}=2.27 MeV; Risø TL-15 reader, Risö National Laboratory, Roskilde, Denmark). A sheet of each of the three films was cut into multiple 2 cm x 2 cm squares. At kilovoltage energy ($E_{hv,Max}$=80 keV), individual film pieces were taped at the surface of a water equivalent phantom (RW3, PTW Freiburg, Germany) of dimensions 30 cm x 30 cm x 15 cm. For exposures with ^{60}Co, the films were placed at the D_{max} position (0.5 cm). The films were irradiated, one at a time, at the center of 10 x 10 cm^2 field while placed perpendicular to the central beam axis. These films were handled in accordance with the precautions recommended in the AAPM Radiation Therapy Task Group TG-55 (Niroomand-Rad, 1998). In order to correlate the signal (in terms of e.g., optical density) to the absorbed dose at the film plane measurements with ionisation chambers were carried out in the field centre prior to the film exposure. An ionization chamber (Roos type TW34001 PTW, Freiburg, Germany) was used for ^{60}Co exposures and an ionization chamber (Radcal, Model 2186, Monrovia, CA, USA) for exposures with kilovoltage x-rays at the same location and depth. The optical densities of the films were measured using a portable densitometer (X-Rite 331 Grand Rapids, MI, USA) and the net optical density (NOD) of each irradiated film was obtained by subtracting the background optical density. The net optical density values were plotted against the absorbed dose values.

Visual readout tests were also performed where ten individuals volunteered to participate. Four were medical physicists, two technicians, two students and two nurses. They were familiar with Gafchromic film and its purpose but had no previous experience evaluating films. The visual test used ten Gafchromic RTQA2 pieces, which had been exposed to absorbed doses ranging from 0 – 100 mGy from the x-ray unit. The films were placed in random order and each subject was asked to grade them from the lowest to the highest dose. The participants were also instructed to identify the exposed films from an unexposed one in a twin-film arrangement, where every film in the current dose range was placed next to a reference unexposed film.

RESULTS AND DISCUSSION

Dose- response curve of each type of Gafchromic film irradiated by a given radiation source were obtained by plotting net optical density (NOD) values against corresponding absorbed doses. These curves for the XRQA and XRQA2 films are shown in Figs. 1a and 1b, respectively.

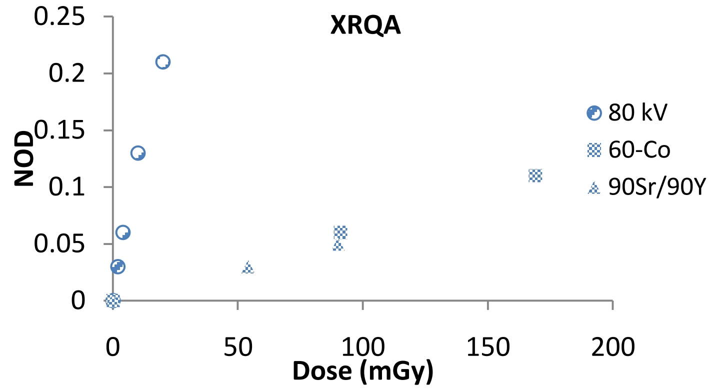

Fig. 1a Dose-response curves of Gafchromic XRQA film irradiated with an x-ray system (80 kV), a ^{60}Co unit (1.17 and 1.33 MeV) and a ^{90}Sr/^{90}Y β-source (E_{max}=2.27 MeV), respectively.

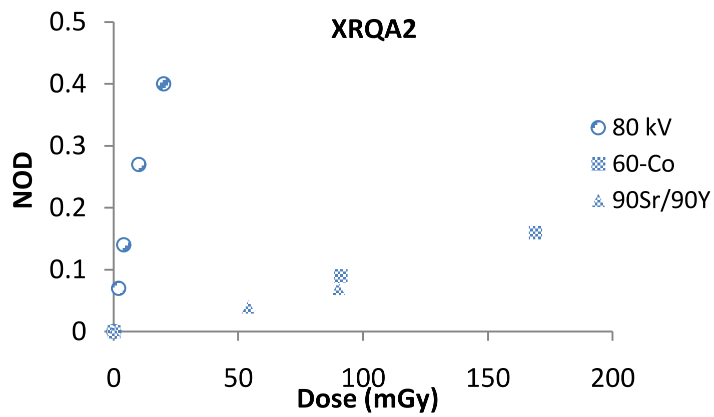

Fig. 1b Dose-response curves of Gafchromic XRQA2 film irradiated with an x-ray system (80 kV), a ^{60}Co unit (1.17 and 1.33 MeV) and a ^{90}Sr/^{90}Y β-source (E_{max}=2.27 MeV), respectively.

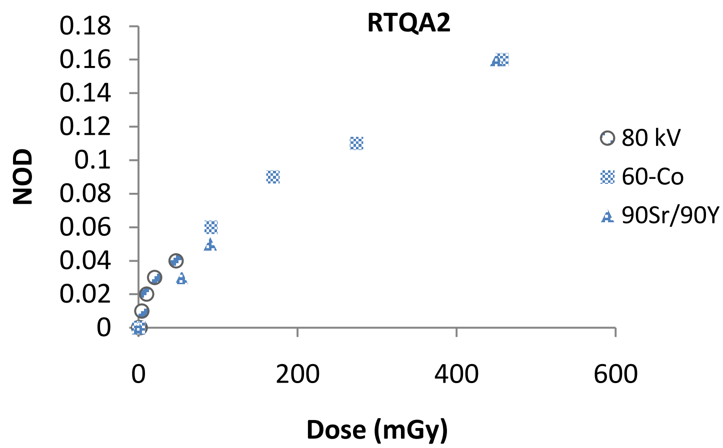

Fig. 1c Dose-response curves of Gafchromic RTQA2 film irradiated with an x-ray system (80 kV), a ^{60}Co unit (1.17 and 1.33 MeV) and a ^{90}Sr/^{90}Y β-source (E_{max}=2.27 MeV), respectively.

An energy dependent dose response is observed for the two films XRQA and XRQA2, with an elevated response for lower (<100 keV) photon energies. The film sensitivity decreases with increasing radiation energy, as expected from the original design idea. The results are consistent with previous reports for XR-type films (Cheung, 2004). These film models contain high-Z materials in the emulsion and have been designed to increase photoelectron interaction, thus increasing its response in the kilovoltage range and making the film more suitable for diagnostic radiology. This leads to an increased energy dependence when used in photon irradiation fields of a larger energy range. The energy dependence of these films therefore disqualifies them as personal dosemeters for first responders. The response for the film aimed for therapy applications, RTQA2, does not, however, exhibit any energy dependence, Fig 1c. The latter film type is thus the best candidate in terms of minimal energy dependence of the response.
The results of the ten observers when asked to visually grade the exposed films from lowest to highest absorbed dose are shown in Fig. 2a.

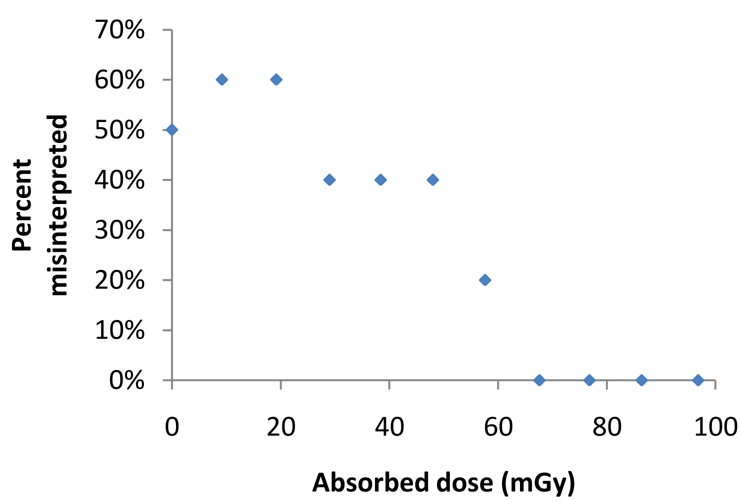

Fig. 2a Results for the participants when asked to visually rank the exposed films from lowest to highest dose.

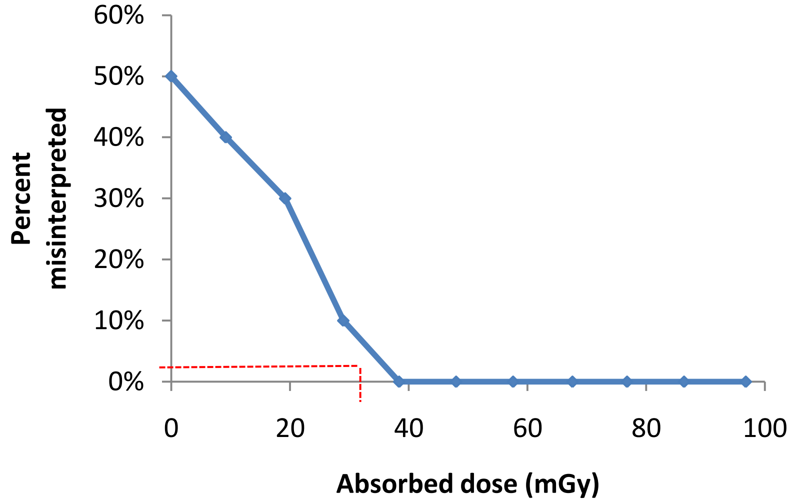

Fig. 2b Results when participants ranked exposed films placed next to unexposed. 5% likelihood of misinterpretation is marked in the plot.

Fig. 3 Visual comparison of an unexposed film and an exposed (47 mGy), shown side-by-side where the exposed film is shown to the right.

There is a variation in visual interpretation and the degree of misinterpretation decreases at higher doses. The performance of the visual readout tests were improved when the subjects were asked to identify exposed films placed next to an unexposed film, Fig. 2b**.** A criterion value of 0.05 would mean that 5% of the observed results would be false negatives at approximately 35 mGy. Thus, at absorbed doses above 35 mGy, this yields a more than 95% probability that the film is identified as being exposed to radiation above the background level. An unexposed film (NOD=0) and a film exposed to 47 mGy (with a NOD=0.03) is shown in Fig. 3 for visual comparison**.** A minimum detectable absorbed dose of 9 mGy was observed, using the densitometer to determine the absorbed dose through NOD. The results show that basic qualitative analysis can be performed visually by comparing colour of the exposed film with colours of unexposed film, down to about 35 mGy. Using a portable densitometer for quantitative assessment can depress the detection limit almost a factor of 4.

CONCLUSION

This study demonstrates that the Gafchromic film RTQA2 can be used as an indicator of dose, giving a visual qualitative absorbed dose estimate down to 35 mGy (corresponding to a risk of 5% false negative). The colour change, alerting the wearer to radiation, is essentially independent of the radiation energy and quality. Its sensitivity is sufficient for accurate measurements of doses in the range of 50 – 500 mGy, making it suitable for monitoring radiation in emergency situations.

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