Radiation Protection Dosimetry (2006), Vol. 120, No. 1–4, pp. 121–124
doi:10.1093/rpd/nci551 Advance Access published on April 27, 2006

EVALUATION OF A NEW SELF-DEVELOPING INSTANT FILM FOR IMAGING AND DOSIMETRY

Y. Watanabe[1,*], G. N. Patel[2] and P. Patel[2]
[1]Department of Radiation Oncology, Columbia University, 622 W168th Street, New York, NY, USA
[2]JP Laboratories Inc., Middlesex, NJ, USA

Radiation sensitive films are standard dosimetric tools in radiation therapy. Films are used for machine quality assurance (QA) and treatment planning software evaluation. With the advent of intensity modulated radiation therapy (IMRT), simple and fast imaging technology is needed for patient-specific verification of radiation fields. Conventional radiographic films are often used. Radiochromic films, e.g. Gafchromic films, were recently introduced to the market. But these films have some disadvantages. JP Laboratories have developed a prototype radiochromic film, called SIFID (self-developing, instant film for imaging and dosimetry) with superior performance such that SIFID is unaffected by ambient light for months, stable up to 90°C and can be archived. SIFID is made of polymerisable diacetylene. The film develops blue colour instantly upon absorbing radiation. We evaluated the film for radiation therapy applications. Our preliminary data demonstrate its feasibility as a dosimetric tool for IMRT QA as well as for other applications.

INTRODUCTION

Intensity modulated radiation therapy (IMRT) requires comprehensive quality assurance (QA) specific to patients in addition to periodic QA tests for all components of IMRT treatment planning and delivery systems. One of the patient specific tests is to validate radiation intensity (or fluence) distributions of treatment fields. Current practice is to use radiographic films, i.e. Kodak X-OMAT V films. A drawback of the films is the relatively long time needed to process the films. Radiochromic films, in particular, Gafchromic films (ISP, Wayne, NJ), which do not require processing and are used under room light, do not respond well to the radiation dose level of interest (<200 cGy)(1), have to be stored below ∼60°C and the image can not be fixed for archival. The other method is to use an electronic portal-imaging device (EPID). However, a common EPID system based on liquid ionisation chambers exhibit slow dynamic response; hence, it is not ideal for measuring dynamically modulated fluence distributions. A new generation of EPID systems is now being introduced into clinics. A solid-state-based flat panel EPID system may solve the problems of the current system, but it needs significant financial investment.

In this paper, we evaluated another type of film, SIFID (self-developing, instant film for imaging and dosimetry), which also eliminates wet-film processing. The film was developed by JP Laboratories (Middlesex, NJ)(2). The film develops blue colour instantly upon absorbing radiation. Since the invention of the basic SIFID material in the early 1990s, significant progress has been accomplished in terms of the film quality and characteristics. We will characterise prototype SIFID films from the latest fabrication, ca. 2004. This paper presents preliminary results of our ongoing investigation on medical applications.

*Corresponding author: yw155@columbia.edu

MATERIALS AND METHODS

SIFID film

Diacetylenes are colourless solid monomers. They polymerise to highly coloured polymers either upon thermal annealing or exposed to high-energy radiation, such as short wavelength UV light, X ray, gamma ray, electrons and neutrons(3,4). Polymerisation of diacetylenes is associated with a colour development due to formation of highly coloured polydiacetylenes. For a given diacetylene, the colour intensity of the film is proportional to the radiation dose. Polymerisation of diacetylenes upon thermal annealing (e.g. storage at room temperature) is referred to as thermal reactivity. Polymerisation of diacetylenes upon irradiation with high-energy radiation (e.g. X ray and UV light) is referred to as radiation reactivity. For the development of the dosemeter, we suppressed the thermal reactivity while maintaining the radiation reactivity.

A special formulation containing a proprietary diacetylene, polymeric binder, solvent and shelf life extenders was developed. A dispersion of fine crystals of the diacetylene was prepared according to a process described in US Patent 5,420,000(2). The dispersion was coated on polyester film and dried. The diacetylene coating was then coated with UV absorbing layer and laminated with a 50 μm thick polyester film.

The SIFID film offers the following advantages over other radiation films available commercially.

It is simple, lightweight and inexpensive[5]. SIFID is made from symmetrical diacetylenes, which are less expensive to make compared with asymmetrical diacetylenes used for Gafchromic films that require more steps to make, and the proprietary processes used for making SIFID are less expensive. It is a self-developing instant film. The colour development is irreversible/permanent and cumulative. The sensitivity of the film can be varied for a broad dose range between 5 and 1000 cGy. The film can be made to respond to various types of radiation such as low-energy (~10 keV) to high-energy (~10 MeV) photons, electrons, neutrons, protons and ions. Colour development is essentially independent of energy and dose rate. It will be tissue equivalent, i.e. mass density of ~1.1 g cm^{-3}. It is unaffected by UV/sunlight for a few days and up to almost 90°C. The visible light or visible laser light has little or no effect on SIFID and does not introduce polymerisation. Hence, it can be used under any ambient conditions. It shows little effect of irradiation temperature (<0.1% per °C between −20 and 60°C). The image formed on films can be archived by heating the film above a pre-determined temperature (e.g. >110°C).

Film characterisation

To estimate photon interaction characteristics of the SIFID material, we calculated the effective atomic number, the electron density and the photon attenuation coefficient as a function of photon energy. We calculated the atomic fractions of component atoms, H, C, N and O, by using the mass density of 1.02 g cm^{-3} for the SIFID material. The photon attenuation coefficients for the component atoms were obtained from standard data sources[6].

The sensitivity of SIFID to room light (~1000 lux), under which the films will be used for medical applications, was investigated by placing an unirradiated film in an office under constant room light, or fluorescent light for 3 weeks. The room temperature during this time varied from 22 to 25°C. The change of the film characteristics was monitored by periodically measuring the optical density (OD) with a point-densitometer, Densitometer Model 07-443 manufactured by Nuclear Associate (Carle Place, New York, NY). We also compared SIFID and Gafchromic film by exposing those side-by-side to direct sunlight and observing the temporal colour change.

Optical characteristics measurements

The absorbance spectra of the SIFID material were measured for unirradiated and irradiated samples. At Columbia University we used Agilent 8453E UV-Visible Spectroscopy System (Waldbronn, Germany).

OD was measured with four instruments. We used two point-OD measurement tools: Densitometer Model 07-443 and Radiochromic Densitometer Model 37-443 both manufactured by Nuclear Associate (Carle Place, New York, NY). The spatial distributions of OD were measured with a flatbed colour image scanner, Model JX-330, (Sharp Electronics Corporation, Mahwah, NJ) and with the VADIR 12Plus film scanning system (VIDAR Systems Corporation, Herndon, VA).

Calibration data for OD vs. absorbed dose were obtained by irradiating SIFID samples to known doses with a 6 MV photon beam from a Varian 2100CD linear accelerator (Varian Medical Systems, Palo Alto, CA). Temporal variation of OD after irradiation was monitored by measuring OD periodically for 3 weeks.

The dependence of film sensitivity on photon beam energy was investigated by irradiating the films with 6 and 18 MV photon beams.

The optical noise level was evaluated by irradiating SIFID films with a 10 cm × 10 cm uniform photon field. The films were scanned with both the Sharp JX-330 and VIDAR scanners. The mean and standard deviation of pixel values (not OD) inside a small region near the centre of the field were calculated. The signal-to-noise ratio (SNR) was then calculated by dividing the mean value with the standard deviation.

Applications to IMRT

SIFID films were evaluated for photon fluence measurements. The films were irradiated with a 6 MV photon beam of Varian 2100CD in polystyrene phantom at a depth of 1.5 cm (or the depth of dose maximum). A film was irradiated with an intensity-modulated field, which was one of six fields used to treat a prostate cancer patient. The IMRT treatment plan and the dynamic multileaf collimator file were generated with the Cadplan/Helios treatment planning software (Varian Medical Systems, Palo Alto, CA). The maximum dose was ~50 cGy. The same fluence distribution was also measured with X-OMAT V (XV) films (Eastman KODAK Company, Rochester, NY) under the same condition.

RESULTS

Film properties

Photon interaction

The electron density and the effective atomic number of the SIFID material are 3.33×10^{23} electrons cm^{-3} and 6.3. The electron densities of water and muscle are 3.34×10^{23} and 3.45×10^{23} electrons cm^{-3}. The effective atomic numbers are 7.5 and 7.3 for water and muscle, respectively. The mass attenuation coefficient of SIFID is smaller for the photon energy <100 keV than water and muscle because of its low effective atomic number. In the energy range between 100 keV and 20 MeV, the agreement between SIFID and water/muscle is within 2%.

Radiation sensitivity

OD of unirradiated SIFID films did not change within the measurement uncertainty for 3 weeks under room light condition. When compared side-by-side, SIFID develops barely noticeable blue colour after a few hours of exposure under the direct sunlight while Gafchromic film develops intense blue colour under the identical conditions.

Figure 1 presents OD as a function of absorbed dose ranging from 0 to 200 cGy. The curve shows slight non-linearity of the radiation sensitivity; in particular, the radiation sensitivity saturates >180 cGy. OD values of SIFID are smaller than the values for radiographic films. Figure 1 represents three sets of data for OD measured just after irradiation, at 12 h, and at 394 h (16 d) post-irradiation. The sensitometric curves changed over the time of 16 d. Noticeable increase of OD occurred before 12 h post-irradiation and the change slowed down afterwards.

The radiation sensitivity of SIFID was the same for 6 and 18 MV photon beams within the measurement uncertainty.

Optical characteristics

When the SIFID films were visually inspected, we could easily notice that the blue colour became darker as the dose was increased; and 5 cGy was sufficient to make visible colour change. The absorbance spectrum measurements showed two peaks at

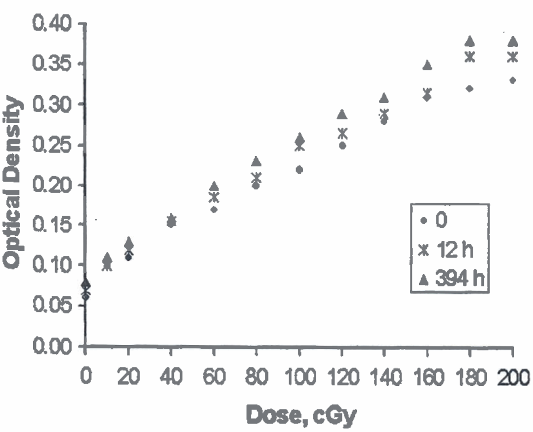

Figure 1. OD vs. dose. This shows three datasets of ODs measured at 0, 12 and 394 h after irradiation.

568 nm (green) and 618 nm (yellow). The 618 nm peak was much higher than the 568 nm peak. The peak heights increased with increasing dose.

The Gafchromic densitometer, which emits red light, did not show any change of the reading with irradiated SIFID films. The regular densitometer, the VIDAR scanner and the Sharp JX-330 scanner gave approximately the same ODs. This is easily understood because these devices use light sources with broad spectrum.

SNR of uniformly irradiated SIFID films did not depend on the scanner type. It was 16 and 18 for the Sharp JX-330 and the VIDAR scanners, respectively. These values are much smaller than that of the XV films (or SNR = 800).

Dose distribution measurement

SIFID films irradiated with an IMRT field showed the fluence distributions. The outline of the field was clearly visible. The fluence variation was easily recognisable. The contrast was sufficient to visually compare the measured distribution with the planned fluence distribution.

Figure 2a and b show the fluence distribution measured with an XV film and a SIFID film, respectively. SIFID captures the major fluence variation observed in the XV films. The 50% isodose line shows the outline of the irradiated field. Some of the hot spots inside the field are also visible. However, the SIFID image also indicates some recognisable difference from the XV film image.

DISCUSSION

Radiochromic films (or Gafchromic films) recently became commercially available. The films are made of tissue-equivalent material and these can be used under room light. The radiation sensitivity, however, is low. For example, the published data shows that Gafchromic films generate an OD of 0.33 for exposure of 100 cGy. However, the background OD of the Gafchromic films is 0.31, whereas it is 0.08 for SIFID. Refer to Table II in Ref. (1). Hence, although the SIFID films produce smaller OD for the same dose than the Gafchromic films, the image contrast of the SIFID film should be better than that of the Gafchromic films at the 100 cGy levels.

The red light source used with the radiochromic film densitometer cannot be used with SIFID film. The radiochromic film densitometer is optimised to measure the absorption spectrum at 671 nm. However, the absorption spectra of SIFID show no change of absorption at this wavelength with increasing dose. A diffuse light source with broad light spectrum used for regular densitometers works with SIFID. Further optimisation of light spectrum, for example, a use of yellow light source, for

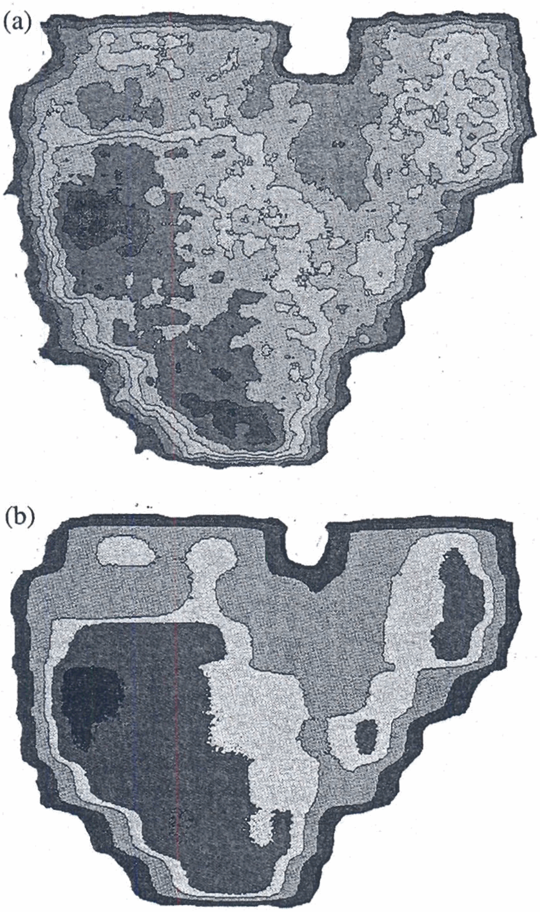

Figure 2. IMRT dose distributions: (a) Kodak XV film and (b) SIFID film.

OD measurements of SIFID should improve the precision of film densitometry.

CONCLUSIONS

This paper has presented preliminary results on the evaluation of prototype SIFID films for radiation therapy dosimetry. We have demonstrated that the SIFID film can be used to instantly visualise photon-fluence distributions of IMRT fields for routine QA. The process eliminates the wet-film processing of regular radiographic films. The films can be used to record clinically relevant dose. The films are not susceptible to room light. Hence, the films do not require packaging for protection against either UV or visible light.

Quantitative dosimetry with the SIFID films is possible. To increase the change in OD against radiation dose, the film scanning system should be optimised to take advantage of the specific characteristics of SIFID absorbance spectrum. With further improvement in the manufacturing process, SIFID films have the potential to replace the existing radiochromic films in terms of radiological imaging capability for practical applications.

ACKNOWLEDGEMENTS

This work was funded in part with government support under contracts from the US Department of Defense and Technical Support Working Group (TSWG) with funding also provided by the Department of Homeland Security, Department of State and Department of Justice through TSWG. We acknowledge Mr Ken Podeko for his technical support on this project. The IMRT plan for this study was created by the medical physics group at Columbia University (Dr C.-S. Wuu *et al.*).

REFERENCES

1. Niroomand-Rad, A., Blackwell, C. R., Coursey, B. M., Gall, K. P., Galvin, J. M., Mclaughlin, W. L., Meigooni, A. S., Nath, R., Rodgers, J. E. and Soares, C. G. *Radiochromic film dosimetry: recommendations of AAPM Radiation Therapy Committee Task Group 55*. Med. Phys. **25**(11), 2093–2115 (1998).
2. Patel, G. N., Cheng, Y.-M. and Patel, S. H. *Heat fixable high energy radiation imaging film*. US Patent No. 5,420,000, JP Laboratories, Inc. (1995).
3. Patai, S. and Repoport, Z., Eds. *Chemistry of Triple-bonded Functional Groups*. (Chichester and New York: Wiley) (1983).
4. Ogawa, T. *Diacetylenes in polymeric systems*. Prog. Polym. Sci. 20943–20985 (1995).
5. Patel, G. N. *A low-cost self-indicating radiation dosimeter*. Final progress report for Contract No. N00024-95-C-405, US Naval Sea System Command (1997).
6. Higgins, P. D., Attix, F. H., Hubbell, J. H., Seltzer, S. M., Berger, M. J. and Sibata, C. H. *Mass energy-transfer and mass energy-absorption coefficients, including in-flight positron annihiration for photon energies 1 keV to 100 meV*. NISTIR 4812 (Gaithersburg, MD: NIST) (1992).