An investigation into a new re-useable 3D radiochromic dosimetry material, Presage\textsuperscript{REU}

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\textbf{Purpose:} To investigate the dosimetric properties of a new Presage formulation which exhibits a reversible color change on exposure to radiation. Presage\textsuperscript{REU} offers the intriguing possibility of the first re-useable 3D dosimetry material.

\textbf{Method and Materials:} Small volumes of Presage\textsuperscript{REU} in 1x1x5cm optical cuvettes were irradiated and re-irradiated under a variety of conditions and times to investigate a range of properties including re-usability, dose-rate dependence, dose sensitivity, temporal response, energy sensitivity, and temperature dependence.

\textbf{Results:} The radiation induced change in optical density (OD) was found to be linear with dose after initial and subsequent irradiations. After the first irradiation OD was observed to clear in \textasciitilde2 weeks when stored at room temperature. 3 subsequent irradiations of the same cuvettes showed a very similar strong OD response, although there was a significant increase between this response and that achieve at initial irradiation.

\textbf{Conclusion:} The Presage\textsuperscript{REU} formulation shows strong potential as the first re-useable 3D dosimetry material. When dosimeters are stored at room temperature (~22°C) clearing can occur in 2-3 weeks.

1. Introduction

PRESAGE was first introduced as a material for 3D dosimetry by Adamovics and Maryanski 2006 [1]. Attractive properties included a radiochromic response, facilitating accurate optical-CT imaging, a lack of requirement for an external container, and a robustness to exposure to the laboratory and clinical environment (except for a sensitivity to exposure to UV light). Since then, several formulations have been characterized, and significant variations in temporal responses have been observed [2,3,4]. In most of the formulations we have studied, the optical-density (OD) response is observed to gradually increase with time after irradiation. Recently new formulations were discovered where the reverse has been observed, and the OD change gradually fades or ‘clears’, until the dosimeter returns to approximately its original state. This new formulation has been termed Presage\textsuperscript{REU}, and has an estimated $Z_{\text{eff}} = 8.1$ and density of 1.07g/cm\textsuperscript{3}, with CT number 130 \pm 20 HU. The exact mechanism controlling the rate of reversibility is still under investigation, but is believed to clear due to a new LMG (lueco malichite green) derivative synthesized at Heuris Pharma, LLC (Skillman, NJ). In this work we investigate the key properties of the Presage\textsuperscript{REU} formulation as well as its suitability for repeat irradiations.
2. Materials and Methods

2.1 Cuvette studies
The reusable formulation was initially characterized using small volume studies where optical cuvettes filled with Presage$^{\text{REU}}$ were irradiated in a reference geometry to known doses. A solid water setup (Fig. 1) with bolus was used as the main arrangement. A cuvette-sized depression was removed from a 1.5 cm thick sheet of tissue equivalent bolus enabling cuvette positioning with center at 5.5 cm depth. Cuvettes were irradiated in a 10x10 cm field on the surface of the phantom (SSD=100 cm), with default dose rate of 400 MU/min.

The initial OD dose response of Presage$^{\text{REU}}$ was determined by irradiating 6 cuvettes to doses of 0.5, 1, 3, 6, 10, and 15 Gy. The dosimeters were then stored at room temperature for at least 2 weeks to allow clearing. Re-useability was investigated by re-irradiating the same cuvettes with the same doses as the initial irradiation. The dosimeters were allowed to clear again, prior to subsequent irradiations. This cycle was repeated 4 times. After each irradiation the radiation induced OD change was immediately recorded. Each cuvette received the same dose on subsequent irradiations (e.g. the cuvette that initially received 1 Gy, also received 1 Gy on subsequent irradiations). Optical density (OD) measurements of the Presage$^{\text{REU}}$-filled cuvettes were made pre and post irradiation using the Thermo Scientific Genesys 20 spectrophotometer. Prior experiments determined the optimal scanning wavelength (i.e. where the maximum radiation induced OD change occurred) was 632 nm, which is consistent with previous PRESAGE studies [2]. All further OD measurements were therefore made at this wavelength. The key quantity determined from irradiated cuvettes is $\Delta$OD i.e. the radiation induced change in OD.

2.2 Large volume studies
A preliminary study was initiated to investigate whether the OD clearing phenomena observed in the small volume cuvettes also occurred in larger volumes. To study this, a 10 cm diameter Presage$^{\text{REU}}$ cylinder was irradiated with a simple 2-field 6X plan to 4 Gy at isocenter. The dosimeter was stored in the dark at room temperature and scanned at several time-points after irradiation and over the first 45 days.

3. Results and Discussion

3.1 Small volume cuvette studies
The immediate sensitivity (radiation induced OD change) of the 6 Presage$^{\text{REU}}$ cuvettes exposed to multiple irradiations (doses of 0.5, 1, 3, 6, 10, and 15 Gy) is shown in figure 2. The first irradiation (June 2009) showed a linear relationship between OD and absorbed dose, with a slope of 0.0206 cm$^{-1}$/Gy. 336 hours after irradiation, the OD of each cuvette had reduced significantly and remained stable relative to the 0 Gy control. The sensitivity of the same cuvettes to the second irradiation was very surprisingly observed to increase by a factor of $\sim$2 when compared with the first irradiation. For the next 3 re-irradiations the same sensitivity was observed as on the second irradiation. The last re-
irradiation in March, 2010 showed a slight decrease in dose sensitivity compared to the 3 immediately prior irradiations. Error bars are omitted from the figures due to the magnitude of the errors on the data being smaller than the size of the marker representing each data point.

We speculate that the depressed initial OD response of Presage\textsuperscript{REU} could be due to an aging phenomenon, where the sensitivity of Presage\textsuperscript{REU} gradually increases over the first few weeks after manufacture as the dosimeter gradually completes the curing process. Some support for this interpretation came from another experiment involving a different batch of the same formulation. 3 cuvettes were irradiated after storage for a month at room temperature (~22°C), where full curing had presumably occurred. The initial dose sensitivity was now found to be 0.0432 Gy\textsuperscript{-1}, similar to the higher sensitivity reported in figure 2. The rate of decay of the OD in the 6 cuvettes after the first irradiation is shown in figure 3.

3.2 Large volume study

Figure 4 shows the decay of the signal in the dosimeter over a 42 day period. Images in (a) and (b) are prescan corrected reconstruction images of the dosimeter windowed identically. Inspection of the figure shows the radiation induced attenuation is clearly fading over time.

4. Conclusions

A new type of Presage is shown to have potential for re-useability. This represents a notable milestone in the history of 3D dosimetry. Our preliminary results from irradiating small volumes of Presage have found that 5 re-irradiations are feasible, with the background returning to near baseline after each. The data suggests that many more irradiations would also be feasible. Several observations warrant further study, in particular: the rate of clearing after each irradiation (may be
slightly increased), the sensitivity with time after curing and repeat irradiations, and any volume effect (effect of size of dosimeter on re-useability and sensitivity). A full characterization of PresageREU is currently being conducted.

![Figure 4](image-url)

**Figure 4.** Optical clearing of a large volume dosimeter over a 43 day period. Reconstruction images (a & b) at the same angle windowed identically to show the decay in the attenuation coefficient over time. (c) Line profiles of (a) and (b).

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**References**

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