On the Feasibility of Verification of 3D Dosimetry Near Brachytherapy Sources Using PRESAGE/Optical-CT

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Purpose: The feasibility of using the PRESAGE/Optical-CT system for 3D dosimetry verification around a brachytherapy source is investigated. Method and Materials: Brachytherapy dose distributions were obtained by irradiation of cylindrical PRESAGE volumes 6cm in diameter by 8cm height with a GammaMed 12i Ir-192 HDR unit (Varian Medical Systems). A narrow channel on the central axis was created by setting a steel catheter in the Presage during manufacture, enabling measurements close to the source (~3mm). Results: Comparison of dose line profiles shows good agreement between PRESAGE and verified calculated dose calculation, in both high and low dose regions. Conclusion: The PRESAGE/Optical-CT shows good potential in verification of 3D dose distributions around brachytherapy sources.

1. Introduction
The goal of brachytherapy dosimetry is to determine the absorbed dose to water surrounding the brachytherapy radiation source. The current gold standard for absolute dose measurement is based on TLD dosimeters [1,2]. Absolute dosimetry with TLD dosimeters require corrections for the difference in the reference and measurement geometry as well as large corrections for the dosimeter specific energy response function. Other dosimeters such as polymer gels, radiochromic film, and diamond detectors have been used [3,4], but require further demonstration and comparison with established Monte Carlo techniques [5,6].

The PRESAGE/optical-CT 3D dosimetry system has potential to measure high resolution 3D dose distributions [7,8], and therefore potential for brachytherapy dosimetry. The lack of requirement for an external container offers potential for acquiring data closer to the source that may be achieved with other approaches [3]. This work presents a preliminary evaluation of three brachytherapy formulations with simple Ir-192 irradiations. Measured dose distributions are compared with verified calculated dose distributions from a treatment planning system.

2. Materials and Methods
2.1. The PRESAGE/Optical-CT dosimetry system for brachytherapy
The dosimetry system consists of an optical computed tomography (Optical-CT) scanner and the radio-chromic PRESAGE dosimeter. PRESAGE is a radio-chromic solid polymer for dosimetric verification of ionizing radiation [9]. The dosimeter is made up of an optically clear polyurethane matrix that is doped with a free radical initiator and a leuco dye called leucomalachite green (LMG,
Sigma-Aldrich, St Louis, MO). More detailed information can be found in previous work characterizing PRESAGE [7,8].

The optical-CT scanning was done with the Duke Mid-sized Optical-CT Scanner (DMOS) an in-house CCD based telecentric system illustrated in Figure 1. This scanner has a 9 cm x 11 cm field of view (FOV) with each pixel in the projection images of size ~80microns, providing exquisite spatial resolution for small dosimeters. A telecentric system has advantages for optical scanning through acquisition of true line integrals through the dosimeter with reduced scatter. For details on telecentric scanning see Thomas et al [10].

![Figure 1. In-house bi-telecentric optical-CT scanner used in the PRESAGE/Optical-CT dosimetry system.](image)

### Table 1. Overview of PRESAGE Formulations and irradiation experiment studied in this work.

| PRESAGE Formulation | Design Characteristics | $Z_{eff}$/CT # | Dose/Irradiation Type |
|---------------------|------------------------|---------------|----------------------|
| 1                   | Near tissue equivalent $Z_{eff}$ and density | 7.5/120±20HU | 20 nominal sec       |
| 2                   | General formulation, temporally unstable (reusable) | 8.1/130±20HU | 700cGy to 1.5 cm     |
| 3                   | Increased sensitivity to radiation | 7.8/90±20HU | 500cGy to 1.5 cm distance |

#### 2.2 Brachytherapy irradiation and imaging experiments

Four cylindrical PRESAGE dosimeters, with different composition as listed in Table 1, with height 10 cm and diameter of 6 cm were supplied by Heuris Pharma LLC. Each dosimeter had 2 mm diameter cylindrical channel in the center to receive the catheters for the HDR source insertion. The channel was manufactured by setting a steel catheter in the polymer prior to curing. A release agent on the catheter allowed easy removal, leaving a channel with clean sides suitable for reducing edge artifacts.

The GammaMed 12it and Plus brachytherapy sources, both manufactured by Varian Medical Systems, were used for the simple irradiations in Table 1. Each consists of an iridium wire core surrounded by a stainless steel cylinder and both have half-lives of 73.83 days. There are only minor deviations in the geometry surrounding the iridium wire core, that result in Monte Carlo calculated dose rate data differences of 1% for $\theta<30^\circ$ and 1% to 5% for $\theta>150^\circ$[3].

#### 2.3 Scanning protocol
The central channel was filled with matching fluid for both the pre and post scans to minimize edge artifacts. The following parameters were used for optical-CT scanning: 900 projections at .2 degree spacing, 5 exposures were averaged to create each projection image used in the reconstruction. Each pixel in the projection image was of dimension 0.0774 mm. Flood field images and dark field images were averaged over 400 exposures. Each projection was flood corrected and reconstructed with an in-house FBP matlab script. Each dosimeter was scanned prior to and after irradiation. The difference between these two 3D image sets, the NOD (net optical density), represents radiation induced change in OD. The NOD is proportional to absorbed dose, and was converted using a normalization reference point based on the specific irradiation type, which is listed in Table 1.

2.4 Image Registration and Analysis
The reference dose distribution is calculated with the treatment planning system Eclipse (Varian Medical Systems) that has been commissioned for clinical use. An x-ray CT scan of each PRESAGE dosimeter was imported into Eclipse for treatment planning. The calculated 3D dose distribution was then imported in to the Computational Environment for Radiotherapy Research software (CERR) [11]. The 3D reconstructed NOD data acquired with the DMOS scanner from the Presage dosimeters were also imported into CERR for comparison and analysis. The calculated and measured distributions were registered in CERR, using the channel in the PRESAGE as a major landmark.

Eclipse and PRESAGE dose distributions for formulation 1 were normalized to 1.0 cm from the source on the transverse plane (r = 1.0 cm and θ = 90°). Dosimeters of formulation 2 and formulation 3 were planned on Eclipse and irradiated to achieve the dose listed in Table 1 at 1.5 cm from source center on the transverse plane. NOD values were normalized to match the prescription (5Gy at 1.5 cm) consistent with using Presage as a relative dosimeter.

3. Results and Discussion
A comparison of Eclipse and PRESAGE formulation 1 coronal dose distributions is shown in Figure 2. Each image has been windowed from 0 to 10 units of dose-rate relative to dose-rate at 1.0 cm from the source center on the transverse axis.

![Figure 2. Coronal slice of Presage measured dose in formulation 1 (left) and the planned Eclipse dose distribution (middle). Color bar values are in Gray. Line profiles on the transverse plane are compared in right image.](image)

Line profiles were taken along the transverse axis from the planes shown in Figure 2 are superimposed in the second image from the right in Figure 2. Good agreement is observed between the PRESAGE and Eclipse line profiles even down to very low doses. Schlerring bands, or regions of different indices of refraction within the dosimeter, were most prevalent in the dosimeter of formulation 2. These bands show up in the dosimeter projections and reconstructions, and are seen in the PRESAGE coronal view in Figure 3 on the right side of the dosimeter. In this case, the bands were about 23 mm from the center of the source as indicated by the large peaks on the right side of the profile. The schlerring bands within the polyurethane matrix appear the major contributor to the noise.
in the PRESAGE data. Despite the relatively higher noise good agreement is again observed in the areas between 5 mm and 20 mm from the center of the source. Data loss occurred in the ±3mm region from the center of source, which was expected because of artifacts from the channel. Figures 2 and 3 show that accurate dose can be measured >3mm from the source.

![Figure 3](image1.png)

**Figure 3.** Coronal slice of Presage measured dose in formulation 2 (left) and the planned Eclipse dose distribution (middle). Color bar values are in Gray. Line profiles through transverse axis are shown in the right panel.

Dose distributions and profiles for profiles for formulation 3 are shown in figure 4, and are surprisingly quite different from the previous two formulations tested. Figure 4 shows the under response of this high-sensitivity formulation in the region within 1 cm of the source channel. The under response is approximately symmetric about the channel.

![Figure 4](image2.png)

**Figure 4.** Coronal slice of Presage measured dose in formulation 3 (left) and the planned Eclipse dose distribution (middle). Color bar values are in Gray. Line profiles through transverse axis are shown in the right panel.

One of the main challenges, and sources of uncertainty, is that of source positioning within the narrow channel. The diameter of the channel is just large enough to allow the insertion of the brachy catheter, but the source can exhibit a slight tilt which is difficult to reproduce. In this work, the source was localized by qualitatively tracing back to the source based on identifying the distribution of dose in the PRESAGE dosimeters and knowledge of the symmetric characteristics of iridium brachy dose distributions.

4. Conclusions
High resolution (~0.5mm³) 3D dosimetry verification around brachytherapy sources appears feasible between ~3 mm and 2 cm from the source using the Presage/optical-CT system. Presage formulations 1 and 2 both show excellent potential for brachytherapy dosimetry. No evidence of an energy response was detected with these formulations to the spectral components of the Ir source. The latter assertion needs further investigation prior to application to lower energy sources.

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