3-D dose verification by cone-beam optical CT scanning of PRESAGE dosimeter

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Abstract. There is a clear need for an accurate and practical dosimeter that is able to verify 3-D dose distributions from complex radiation treatments. The purpose of this study is to evaluate the dosimetric performance of PRESAGE radiochromic plastic dosimeter in conjunction with a cone-beam optical CT scanner, Vista™, for 3-D dosimetry. The cone-beam optical CT scanner presented in this study can perform optical readout in less than 30 min, which makes same day dose verification for treatment possible. For dosimetric accuracy, a complete 3-D dose verification procedures were performed, including dose response calibration with a 12 MeV electron beam, a 6 MV photon square field irradiation, as well as a 5-field IMRT irradiation. This study shows that 3-D dose verification with fast optical CT scan of PRESAGE dosimeter is feasible. First-generation optical CT scanner can be used as a gold standard for optical readout of dosimeters.

1. Introduction
Complex radiation treatment modalities such as intensity-modulated radiation therapy (IMRT) and stereotactic radiosurgery offer the benefit of dose conformity to the target volume and dose sparing for critical organs. Currently, verification of complex dose distribution is predominantly done using dosimeters that only sample part of the three-dimensional dose information [1-3]. This can be partially attributed to the fact that all the reliable and fast QA tools are 2-D dosimeters. This raises the need for an accurate and practical dosimeter that is able to verify 3D dose distribution within 1-2 hours, or allow for same-day treatment. A first-generation optical CT scanner, in conjunction with gels or radiochromic plastic dosimeters, has been successfully used for 3-D dose verification of complex treatments. However, true 3-D scan with a high spatial resolution and a large field-of-view takes many hours to acquire the data for dose reconstruction, which makes same-day dose verification for treatment impossible.

This study evaluates the dosimetric performance of a commercial fast cone-beam optical CT scanner, Vista™ (Modus Medical Devices Inc.), in conjunction with a radiochromic plastic dosimeter, PRESAGE® [4, 5] for 3-D photon dosimetry.

2. Materials and Methods
Radiochromic plastic dosimeters, PRESAGE®, were used for dose measurements in this study. Three sets of phantoms (11.4 cm diameter × 10 cm length) were irradiated. One was irradiated with a 12MeV electron beam for dose response calibration; one was irradiated with a 6MV, 4 x 4 cm square field, and one was irradiated with a 5-field IMRT plan. The PDD matching method using electron
depth dose curve from ion chamber measurement as a benchmark has been demonstrated to be a convenient and relatively accurate way for dose response calibration [6]. The dosimeters were maintained at a temperature of 7°C before and after irradiation. The dosimeters were set to reacclimatize to room temperature of about 22°C, before irradiation and optical-CT readout.

Optical readout was performed using a Vista™ cone beam optical CT scanner (Modus Medical Devices Inc.). The method has been described in a few articles [7, 8]. Additionally, Olding et al investigated its basic properties [9]. The scanner utilizes a LED diffuse light panel and a lens based CCD camera to capture a series of 2D optical projections through the region of interest while the object is being rotated 360°. Initial investigations indicated that cone-beam optical computed tomography of polymer gels is complicated by scattered stray light perturbation [10]. Radiochromic dosimeters such as PRESAGE could be more suitable for readout by a cone-beam optical CT scanner since the optical density change is due to light absorption, not scattering.

Dosimeters are suspended in a liquid-filled aquarium for refractive index matching. A mounting post, glued on the dosimeter, can be locked onto the rotation table of the scanner in only one manner, resulting in an identical position of the dosimeter for each scan. This allows for accurate registration of the pre-irradiation and post-irradiation scans.

A Feldkamp filtered back projection was used to reconstruct the 3D dose map, with a spatial resolution of 1 mm. Each dosimeter was scanned before and after irradiation in order to eliminate artifacts caused by light scattering and dosimeter impurities.

The dose distributions obtained from PRESAGE/Vista scanner were compared with the calculated dose distributions from ECLIPSE treatment planning system (Varian Medical Systems Inc, Palo Alto, CA). One dosimeter was scanned with a CT simulator and the image was transported to the treatment planning system. A five-field IMRT plan was then used to generate a hybrid phantom plan. Both measured and calculated dose distributions were exported to an in-house dose comparison plugin written for ImageJ. (National Institute of Health, Bethesda, MD, USA)

3. Results and Discussion
The comparison of optical densities at depths from the PRESAGE measurement and the ECLIPSE depth dose curve, for a 12 MeV electron field, is shown in Fig. 1a. The dose response curve as determined from electron PDD matching is presented in Fig. 1b. The PDD curves, measured and calculated, agree within 2% and 1mm. The “depth-dose matching” technique has the advantage of acquiring many more data points in modeling the dose response.

![Figure 1: (a) Central axis depth dose comparison between PRESAGE measurement and Eclipse treatment planning calculation for a 12 MeV, 6x6 cm² electron field; (b) Dose response curves of the PRESAGE dosimeter obtained from the electron PDD matching method.](image)

Figure 2 shows a good agreement in isodose lines between PRESAGE measurement and planning calculation, for a 6 MV, 4x4 cm square field. Dose comparison for a single photon square field provides a good baseline of accuracy in dose measurement, since the dose distribution in the planning system is obtained from commissioning beam data.
Figure 2: Comparison of the isodose lines from the PRESAGE measurement (red) and Eclipse planning system (blue lines)

Figure 3 shows dose distribution comparison, for a 5-field IMRT plan, at the central axial plane between measured and calculated dose distributions, with maximum dose normalized to 100%. The agreement is very good from 70 to 100% isodose lines. However, the measured isodose lines are consistently a few percent higher than the calculated isodose line in the region of 50 to 70%. The reconstruction protocol for the cone-beam CT scanner involves subtracting the data set from pre-irradiation reference scan with the data set from post-irradiation scan before it is fed into the back projection algorithm. Considering the lesion used in this study is only 2.5 cc and the dose gradient in such a small area is significant, the reference scan is crucial for correct dose reconstruction.

Figure 3: Comparison of the isodose lines obtained from the PRESAGE measurement with Vista cone-beam optical CT scans (Red) and the Eclipse planning calculation (green lines) at the central axial slice.

Figure 4 shows two grayscale images of the calculated (a) and measured (b) dose distributions of the IMRT plan at central slice. Streaking artifacts are observed in the measured dose distribution (yellow arrows). These artifacts can result from debris in the optical matching tank or from scratches/impurities in the dosimeter.

The pre-irradiation reference scan method is utilized to eliminate most artifact resources, including scattering, scratches on the optical-matching tank and any inhomogeneities contained within the PRESAGE material.
The interest for developing an optical-CT system that utilizes a broad light beam instead of a small laser beam is driven by the demand for a faster optical read out modality. The cone-beam optical scanner presented in this study had a scan time of less than 30 min, which makes same day dose verification for treatment possible. However, all ‘broad beam’ scanners that are currently described in the literature utilize an LED light panel to illuminate the dosimeter during image acquisition. This light source has a distinct polychromatic light emission spectrum. The absorption spectrum of the PRESAGE material is non-uniform. As a result, spectral artifacts arising from preferential absorption can be introduced [11]. In this study, our results showed that the cone-beam optical CT scanner can produce reasonable reconstructed dose, but slightly inferior to the first-generation optical-CT scanner. This result is not surprising since it has been suggested that results obtained with first-generation optical scanner can be used as the ‘gold standard’ when it comes to evaluating the results obtained with broad-beam optical-CT scanners.

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5. References
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