Scatter Corrections for Cone Beam Optical CT

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Abstract. Cone beam optical computed tomography (OptCT) employing the VISTA scanner (Modus Medical, London, ON) has been shown to have significant promise for fast, three dimensional imaging of polymer gel dosimeters. One distinct challenge with this approach arises from the combination of the cone beam geometry, a diffuse light source, and the scattering polymer gel media, which all contribute scatter signal that perturbs the accuracy of the scanner. Beam stop array (BSA), beam pass array (BPA) and anti-scatter polarizer correction methodologies have been employed to remove scatter signal from OptCT data. These approaches are investigated through the use of well-characterized phantom scattering solutions and irradiated polymer gel dosimeters. BSA corrected scatter solutions show good agreement in attenuation coefficient with the optically absorbing dye solutions, with considerable reduction of scatter-induced cupping artifact at high scattering concentrations. The application of BSA scatter corrections to a polymer gel dosimeter lead to an overall improvement in the number of pixel satisfying the (3%, 3mm) gamma value criteria from 7.8% to 0.15%.

1. Introduction
The effects of multiple scatter on the measurement integrity of optical computed tomography (OptCT) for polymer gel dosimetry is an important issue that remains to be addressed. From preliminary work in characterizing the VISTA OptCT scanner [1,2] it appears that optical scatter effects are not unlike in-scatter effects seen in x-ray CT [3]. Different pre-processing and post-processing schemes have been employed in cone beam x-ray CT with varying degrees of success [4] One strategy employs anti-scatter grids to reject X-ray scatter signal prior to image acquisition [5,6]. Another approach is the beam stop method, where an array of opaque disks is added at the beam input side of the scanner [7,8]. Scatter data is then acquired and interpolated to form scatter maps that are subtracted from the image projections prior to tomographic reconstruction. This method has been used in the calculation of stray light values for optical absorption in patent blue violet dye solutions [9], but has yet to be applied to optically scattering media. In this work, we describe the application of anti-scatter polarizers, a beam stop array (BSA) and a beam pass array (BPA) toward the removal of scatter signal from OptCT data. Scatter corrections for standard well-characterized scattering solutions (described in an accompanying paper in these proceedings) and polymer gel dosimeters are investigated.
2. Materials and Methods

Standard scattering solutions based on Duramax B-1000 colloidal latex binder and incorporating 12 wt.% propylene glycol have been prepared in 1 L polyethylene terephthalate (PET) jars. The solutions were evaluated using the VISTA cone beam OptCT scanner and with: (a) a 4mm diameter dot BSA inserted at the front face of the aquarium (see Figure 1), (b) polarizing films placed at the front and back faces of the scanner aquarium, or (c) a 2mm diameter pinhole BPA inserted at the front face of the aquarium. Reference and data scans were taken using 633 nm LED illumination and a 1024x768 pixel CCD camera (410 projections over 360°, 15 minutes per scan). Image reconstruction was completed using Feldkamp backprojection with a Hamming filter, to a 0.5 mm voxel size.

N-isopropylacrylamide (NIPAM) based polymer gels were prepared according to Senden et al.[10] (50 %C, 4%T). Gels were poured into 1 L polyethylene teraphthalate (PET) bottles for imaging and irradiated using a T780 Cobalt-60 tomotherapy benchtop (MDS Nordion, Kanata, Canada) approximately 24 hours post-manufacture using 1x1cm^2 pencil beams. OptCT imaging of the polymer gel dosimeters was completed using the BSA method.

3. Results and Discussion

Both anti-scatter polarizers and BSA corrections yield an improvement in the overall linearity of the VISTA OptCT scanner through rejection of multiple scatter from the signal (Figure 1). However, the anti-scatter polarizer method did not remove the cupping artifact observed at higher solution concentrations despite the appearance of linearity. This method also introduces additional optical artifacts in the projection images that compromise the measurement integrity in some locations.

In comparison, the BSA method extends the range of scanner measurement integrity with significant cupping artifact reduction (Figure 2). As the beam stop array reduces the overall primary

![Figure 1](image)

Figure 1: A 4mm diameter dot BSA was inserted at the front of the aquarium (top left) and average scattered light values determined at the centre of the blockers. These values were used to develop interpolated scatter maps (bottom left) which are subtracted from the reference and data projections prior to reconstruction. Mean reconstructed VISTA CT numbers (right) are determined from a 80 mm diameter, 80 mm high cylindrical region of interest (ROI) along the central axis of the PET jar. Attenuation coefficients are determined from spectrophotometer measurement of the same solution. Error bars are smaller than symbol size.
signal, this is not an exact correction strategy (see Figure 3). However, the corrected scatter solutions show good agreement with the optically absorbing dye solutions in the relationship between attenuation coefficient and VISTA CT number. A finer array dot spacing than the one used in this experiment (16 mm spacing between 4 mm diameter dots) with smaller dots would provide a more

![Figure 2: The application of a BSA scatter correction to a uniform 0.1 g/L phantom scattering solution in a 9 cm diameter PET jar results in a significant reduction (left, C) in the observed cupping artifact (left, A) and overall increased average attenuation value (right). Polarizer corrected data (left, B), shows an increased average attenuation value, but without significant cupping artifact reduction. Highly absorbing uniform patent blue violet dye solutions display a bowed attenuation profile (left, D) consistent with results of previous work by Jordan et al. [9].](image)

![Figure 3: Different sized diameter dot beam stop arrays such as the preferred 2 mm array (top left) were inserted at the front of the aquarium and average scattered light values determined at the centre of the blockers. These values were used to develop interpolated scatter maps (as in Figure 1) which are subtracted from the reference and data projections prior to reconstruction. A reduction in scatter signal estimation is observed with increasing blocker dot size (right) along a line in the projection image (bottom left). This result is from increased area blocking of the light source.](image)
accurate scatter map correction near the jar edges and at the central axis, with the additional benefit of reduced primary signal loss from the beam stop array (Figure 3). The 4 mm BSA blocks close to 5% of the light source intensity, whereas an equivalent 2 mm BSA would block only 1%.

Application of the BSA scatter correction method to polymer gels irradiated with a pencil beam calibration pattern leads to considerable improvement in the dosimetry (Figure 4). The middle third of the gel dosimeter is particularly susceptible to scatter artifacts. In a comparison of the calculated reference and OptCT measured dose distributions, 2D gamma values greater than 1 may be observed in 7.8% of the pencil beam calibration pattern pixels within this region. This can be reduced to less than 0.2% pixel failure with a BSA scatter correction, even in gels irradiated with highly scattering pencil beams.

Figure 4: A 4%T polymer gel dosimeter irradiated with a 500 cGy intersecting pencil beam pattern (left) shows significant pixel failure (7.8%) for 3%, 3mm 2D gamma criteria (centre). A BSA scatter correction applied to the OptCT data reduces pixel failure to 0.15% (right).

Figure 5: Evaluation of the light intensity along a line in the projection image of a 4%T polymer gel dosimeter irradiated with a 400 cGy test prostate plan (OptCT projection, top left). The BPA method (bottom left) yields a closer approximation (right) of the primary to scatter signal than the BSA method.
OptCT projection data from polymer gels irradiated with a larger scatter volume test prostrate plan is shown in Figure 5. As previously stated, the BSA method underestimates the scatter signal due to blocking of primary signal from the light source. An alternative method of scatter correction utilizes a beam pass array, which essentially consists of a grid of 2 mm diameter pinholes. In this method, the primary OptCT signal is estimated from the pinhole points, then subtracted from the raw OptCT projection (primary + scatter) to obtain the scatter signal at the pinhole point. The scatter values at the pinhole points are then interpolated using a bicubic spline to form a scatter map as in Figure 1. While the BPA method does not suffer from inaccuracy due to blocking of primary signal, it is significantly perturbed by refraction effects and minor imperfections in the gel dosimeters at different projection angles, leading to streak artifacts in the reconstructed image. Further results are forthcoming on the development of adaptive BSA and BPA scatter maps correcting individual projections prior to image reconstruction.

4. Conclusions
Beam stop array and beam pass array corrections have exciting potential for multiple scatter corrections of cone beam OptCT in polymer gel dosimetry. While BSA scatter corrections are limited in cone beam x-ray CT by the realities of increased x-ray dose and acquisition time, the benefits to cone beam OptCT are well worth the time afforded to such corrections. Irregularities in the reference scan (i.e. the base level of the dosimeter) are well-addressed by such corrections and adaptive scatter maps correcting individual projection images prior to reconstruction have promise to provide further correction to artifacts introduced in highly scattering irradiated dosimeters.

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6. References
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