Linearity and image uniformity of the Vista™ optical cone beam scanner

Kevin Jordan and Jerry Battista
London Regional Cancer Program – London Health Sciences Centre
Departments of Medical Biophysics and Oncology, University of Western Ontario

1. Introduction
Several optical computed tomography (CT) scanner geometries have been demonstrated for application to 3D gel dosimetry. The scanners fall into two classes: single-ray detector and broad beam - array detector. Two broad beam geometries, divergent cone beam [1] and collimated beam [2] are possible and each geometry has features worth evaluating. The optical properties of specific dosimetric gels may make certain scanner geometries preferable. For example, highly scattering gels may require single-ray detector scanners for optimum readout and fast scanners may be necessary for gels in which the radiation products diffuse more easily.

This report is an initial evaluation of the Vista™ optical cone beam scanner (Modus Medical Devices, London Canada). Results from this first research model will assist in identifying improvements required to make a system for accurate clinical 3D gel dosimetry.

The initial test involves scanning coloured transparent solutions and comparing optical CT attenuation coefficients with independent measurements of the solutions obtained with an absorption spectrometer. For such transparent solutions, optical attenuation is due primarily to absorption. Quantitative agreement must be established with these low scatter systems prior to evaluating densitometric and dosimetric performance with highly scattering gel materials.

2. Methods
Aqueous solutions of a dye, patent blue violet, were prepared. All optical density measurements were referenced to water. Transmission measurements in 10 cm pathlength cuvettes were performed with a Hitachi – Perkin Elmer model 204 absorption spectrometer immediately following optical CT scanning. For those solutions with transmission values of less than 5% additional measurements were performed after a 50% dilution in order to minimize the effect due to spectrometer stray light. The Vista scanner was geometrically calibrated according to the procedure outlined in the scanner technical documentation. Sample plastic jars, provided by the manufacturer and the aquarium were completely filled with solutions to minimize reflections from the top surface. The yellow LED light and bandpass filter pair were used. Camera gain was set to minimum, and shutter time was adjusted to a maximum signal of ~75% of full scale. Reconstruction with high resolution mode (410 projections) generated a CT array of 256³ elements in 7 minutes using a dual processor 3 GHz PC. Normalization was enabled to allow correction for small changes in lamp intensity. Reconstructed voxel size was approximately 0.5 x 0.5 x 0.5 mm³. Stray light measurements [3-5] involved acquiring images with black 25 mm diameter “stop” disks placed at the face of the light source blocking the central optic axis and a section of the cylinder wall (figure 1). Stray light values were averaged over the central 6 mm diameter area of the shadow. Stray light values were subtracted from the reference and data scan.
images prior to image reconstruction. A black felt sheet was placed between the camera and object to minimize stray reflections.

Figure 1. Transmission image (camera view) of water with shadow disks for stray light and wall reflection measurements.

3. Results
Initial reconstructions exhibited a spherical volume visible on the optic axis approximately 25 mm diameter with 10% additional attenuation. Investigations determined this “hot spot” was due to reflection from the bandpass filter. Tilting the filter holder downward 5 degrees minimized the reflection in subsequent images.

Table 1 summarizes the comparison of measured attenuation from spectrometer and reconstructed values with the Vista scanner. Manual estimates of transmission are listed in column 1. The mean CT value and standard deviation for a middle, transverse slice averaged over the central 25% of cylinder area are listed in columns 2 and 3 respectively. Spectrometer measurements at 591 nm were selected for comparison since this wavelength gave the best, single wavelength agreement with the in-house optical cone beam system.

Table 1: Comparison of dye solution attenuation coefficients measured with Vista optical CT scanner and absorption spectrometer.

| %T (jar) | $\mu_{CT}$ (cm$^{-1}$) | Std dev $\mu_{CT}$ | $\mu_{spec\ 591 nm}$ (cm$^{-1}$) | $\mu_{CT}/\mu_{591}$ |
|---------|------------------------|------------------|-------------------------------|----------------------|
| 83      | 0.0280                 | 0.00087          | 0.0266                        | 1.053                |
| 28      | 0.143                  | 0.0013           | 0.144                         | 0.993                |
| 17      | 0.1956                 | 0.0015           | 0.198                         | 0.988                |
| 8       | 0.2944                 | 0.0024           | 0.295                         | 0.998                |
| 0.8     | 0.6030                 | 0.014            | 0.567                         | 1.064                |
Figure 2. Reconstructed attenuation coefficients for dye solution; a) central profile for middle height slice b) mean attenuation along central rotation axis.

For the transmission data, reflection from the jar outside wall introduces an inconsistency into the projection data. This reflection contributes to a bowed reconstructed profile and becomes a larger effect for darker samples. The magnitude of stray light also has an influence on the uniformity of the reconstructed attenuation coefficients. Further measurements will determine appropriate values for this particular geometry and specific sample jar. Figure 2a shows a reconstructed central profile and figure 2b summarizes the bottom to top increasing attenuation trend. A multi-point manual calculation correcting for local stray light agrees with this trend. This suggests the top to bottom non-uniformity is present in the raw data. The cause of this error has yet to be identified.

4. Discussion
The quantitative agreement (<2% difference) between spectrometer and Vista scanner attenuation coefficients for slices near optic axis indicates there are no large instrumental or reconstruction errors in this system. Differences for high transmission (>70%) samples require further investigation. Strongly attenuating solutions with transmissions of less than 2% will require corrections for reflections near the jar wall present in the raw images. It is anticipated that spectral “hardening” will occur in strongly attenuating samples but this does not appear to be a dominant effect at the 1% transmission level. Future comparisons will employ a solution with uniform absorption over the spectral width of the scanner source and filter to minimize spectral hardening as a confounding variable.

A simple constant correction for stray light in uniformly attenuating, transparent samples provides improves agreement between reconstructed attenuation and spectrometer measurements. Optimum stray light values minimize the importance of corrections for reflection at the cylinder walls. Tilting the bandpass filter, minimized reflected stray light in the data images and improved the uniformity of the reconstructed liquid attenuation coefficients.

5. Acknowledgements
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6. References
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