Optical computed tomography liquid calibration phantom

K Jordan
London Regional Cancer Program (London Health Sciences Centre), Department of Medical Biophysics, Western University, London, ON, Canada

E-mail: kevin.jordan@lhsc.on.ca

Abstract. Fluorinated ethylene propylene tubing is investigated as a method of preparing a contrast-resolution phantom for quantitative characterization of optical CT scanners and hydrogel dosimeters. Two sizes of tubing were examined: 6 and 13 mm inner diameter with 0.75 and 0.5 mm wall thicknesses, respectively. Water solutions of carbon black, nanoparticles in micelles provided continuously adjustable absorption contrast. Cross-sectional slices from two phantoms scanned with two different optical CT scanners are presented. Reconstructions from these simple phantoms can be used to identify scanner artefacts and improve instrument design. These phantoms represent a more reproducible approach than casting "gel fingers" into gel phantoms for system characterization. The thinner walled tubes have fewer optical artefacts.

1. Introduction

Optical computed tomography (CT) for 3D radiation dosimetry has many features in common with x-ray CT. In fact, a dedicated optical CT scanner, DeskCAT Modus Medical Devices Inc. is under development for the purpose of teaching the principles of x-ray CT. Clinical x-ray CT scanners provide a market for the commercial development of dedicated phantoms for standardized performance testing. For example, the Catphan® phantom from The Phantom Laboratory, is commonly used to test contrast, linearity, uniformity and spatial resolution. This company also provides several liquid-filled phantoms for nuclear medicine and magnetic resonance imaging QA. Optical CT is a much smaller market with limited commercial phantoms for QA purposes. There are several types of 3D dosimeters under investigation. These include transparent radiochromic hydrogels and plastics and polymerization hydrogels. The performance of these dosimeters is partly limited by the optical properties of the vessel containing the material. In summary, the scanner, dosimeter and dosimeter vessel all contribute to the overall performance of various 3D dosimetry systems. In x-ray CT, scanners and reconstruction software are commonly compared using a standard QA phantom, such as the Catphan® phantom. Analogous phantoms will assist in deployment of quantitative optical CT.

Contrast "finger phantoms" prepared by pouring coloured gel into tube shaped holes in gelatin phantoms for optical CT studies have be reported. Food colouring dyes were first reported by Oldham [1] and Kristajic [2]. However the dye diffused from the fingers limiting there value for comparative studies. A non-diffusing colloidal gel finger phantom based on contrast from scatter was characterized by Bosi [3, 4]. Carbon black (CB), nanoparticle, non-diffusing gel finger phantoms were then reported by Jordan [5]. With hydrogen peroxide antimicrobial treatments, this latter phantom remained stable for over two years. However, preparation of gel finger phantoms is time consuming and each phantom is likely to have unique optical characteristics. Clear fluorinated ethylene propylene (FEP) thin-walled tubes has been used as cylinder walls for gels in optical CT because of the near refractive index match to several hydrogel formulations [6]. In this report initial results from aqueous "finger" phantoms for characterizing 3D dosimetry systems are presented. The work focuses on water-equivalent, hydrogel dosimeters with refractive indices near 1.34 but could be adapted to higher refractive indices for other materials. The tubes can be filled with coloured solutions to provide a range of contrasts for scanner system evaluation.

Rahman et al [7] have reported high resolution test phantoms based on irradiation of the radiochromic plastic Presage® by synchrotron beams. The paper provides a thorough discussion of the developments and needs related to phantoms for QA of optical CT – 3D dosimetry systems.

2. Methods

Two samples of FEP tubing were investigated: 1) tubing, VWR #63014-695 OD:ID 7.9:6.4 mm 2) thin-walled heat shrink tubing, Newark SKU# 92N6000, OD:ID 13.5:12.5 mm. The smaller diameter tubing was straightened by sliding over 5 mm diameter glass rod and annealing at 100 C. Top and base rings were machined from polymethymethacrylate to hold the tubes rigid. In the first case, this 4 tube phantom was placed in a PETE jar for scanning with a modified Vista10 optical cone-beam (CBCT) scanner, Modus Medical Devices Inc. The tubes, jar and aquarium were filled with an 8.3% by mass, propylene glycol in water solution. The sample was scanned with 590 nm light, 512 projections per 360 degrees, camera lens aperture of F4 and 8 minutes scan time. Next, the reference solution was replaced with refractive index matched carbon black solutions in 3 of the 4 tubes and the CT scan repeated. Reconstruction was performed with 0.25 mm^3 voxel size and Ramp filter, 512^3 array. A photograph of the phantom is shown in Figure 1. A second fan beam scan set was collected by inserting a pair of horizontal slots to vertically collimate the beam.

The second case consisted of 4 thin-walled tubes pressed into holes drilled in a plastic plate. Thermal annealing to straighten theses tube was not performed. The phantom was mounted in an in-house prototype laser scanning cone-beam CT scanner (details of scanner presented in separate conference submission). The tubes and aquarium were filled with water and scanned with 594 nm laser light, 512 projections per 360 degrees, 30 minutes scan time. Next, the water was replaced with carbon black solutions in 2 of the 4 tubes and the CT scan repeated. Reconstruction was performed with 0.34 mm^3 voxel size and Ramp filter, 512x512x200 array. A photograph of the phantom in the aquarium is shown in Figure 2.

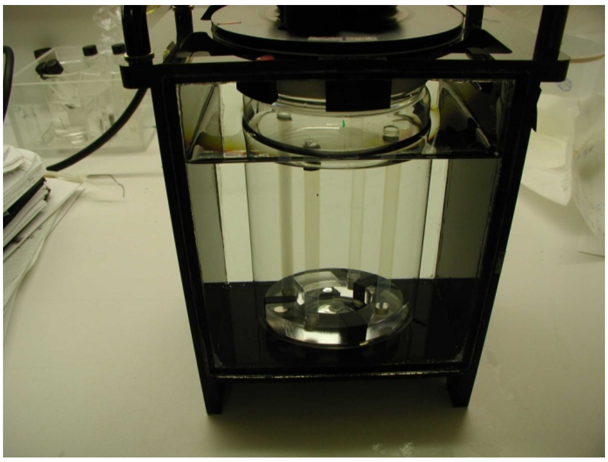

Figure 1: Photograph of 6 mm diameter FEP tube phantom with 3 tubes filled with carbon black solutions and 4^{th} with refractive index matching liquid.

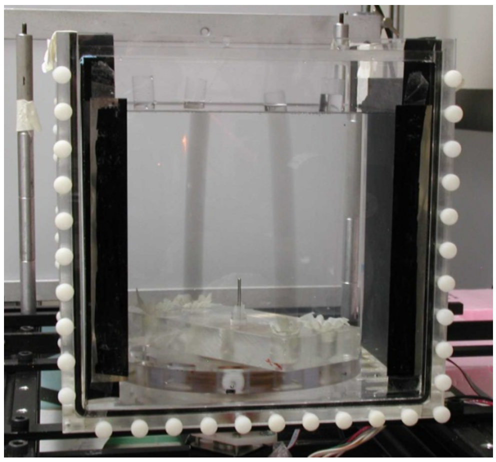

Figure 2: Photograph of 13 mm diameter FEP tube phantom in water filled aquarium: 2 tubes filled with carbon black solutions and 2 tubes with water (see tops of tubes above water level).

3. Results and Discussion

The middle slice of the 3D reconstruction for the smaller diameter tube phantom is presented in Figure 3. Several artefacts are present in the reconstruction examples include streaking between the tubes, gradients within tubes (note the higher attenuation of lightest CB solution on side facing darkest CB solution) and ghost images of CB tubes. The ghost images are likely the result of small differences in the refractive indices of the 3 CB solutions and position of the phantom for the reference and data scans. The fourth tube reconstructed as a single tube and contained the same solution for both scans. Independent comparison of attenuation coefficients with an absorption spectrometer were not performed at the time of CT scans. The next day black films were observed on the beakers storing the samples indicating instability of these CB solutions. Attenuation coefficients for the fan versus cone beam geometry scans were approximately 10% greater, consistent with other stray light studies. The reconstructed and nominal diameters of the reference tube agreed within one voxel or 0.25 mm of each other.

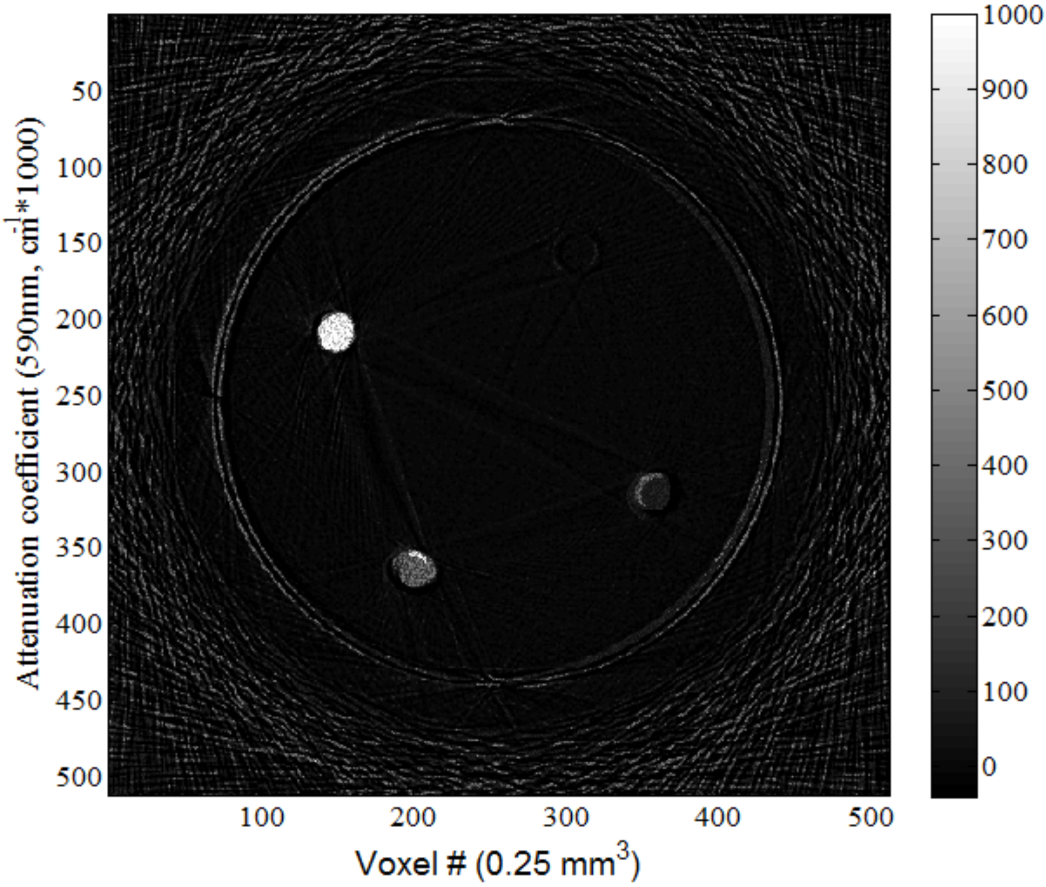

Figure 3: Middle slice from 6 mm tube phantom with carbon black solutions, scanned with modified Vista10 CBCT. Note artifacts in tube uniformity due to position changes between reference and data scans. Phantom mounted in PETE jar, walls and seams are evident.

In Figure 4, the middle slice of the 3D reconstruction for the 13mm diameter tube phantom is shown. The refractive index mismatch is larger with water, but the perturbations are smaller due to the thinner tube walls. This phantom highlights a simpler system with no vessel to introduce additional artifacts, such as external reflections near grazing incidence. Adjusting window and level allows small ring artifacts to be observed as well as an increasing background with an inverse radial dependence, indicating some artifacts are due to reflections within the aquarium itself. Mean attenuations in the tubes averaged over 2mm^3 volume at mid height were 0.090, 0.210 and 0.425 compared to spectrometer readings in 100mm long cuvettes of 0.098, 0.220 and 0.452 cm^{-1}. Results are around 5% low indicating scatter within these tube samples is not entirely eliminated in the laser cone beam CT data set.

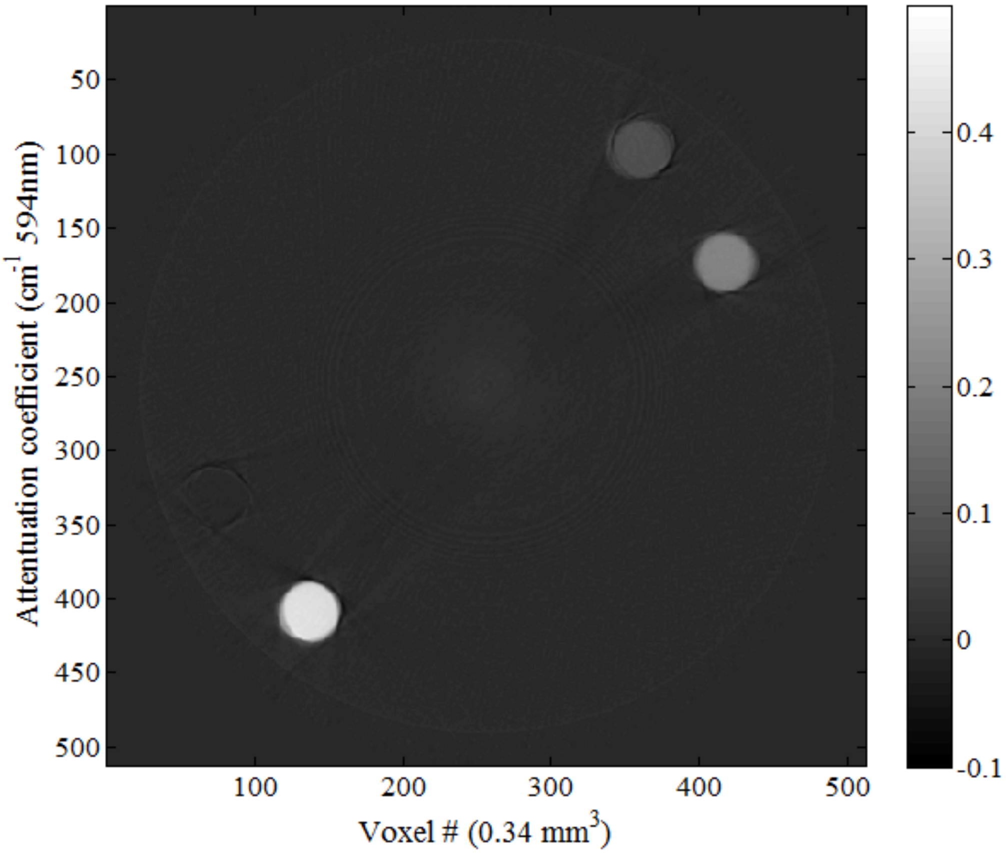

Figure 4: Middle slice from 13 mm tube phantom with carbon black solutions, scanned with laser CBCT. Note ring artefacts due to reflections within aquarium. Increased attenuation near rotation axis also related to reflections.

4. Conclusion

FEP tubing has several favourable properties for preparation of optical CT QA phantoms. Such as clarity, refractive index, chemical inertness and plasticity. Aqueous solutions are inexpensive to prepare and biodegradable formulations of different colours and degree of scatter can be prepared. Black solutions are of particular interest because of the low sensitivity to wavelength and bandwidth of various optical CT light sources. These phantoms are useful since refractive index, scatter and absorption coefficients can be continuously tuned for specific tests.

5. References

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