Three-dimensional reproducibility assessment of radiochromic ClearView™ gel in custom vessel

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Abstract. Samples of the radiochromic hydrogel ClearView™ were characterized for 3D dosimeter performance in custom vessels and read with a modified Vista16 optical cone beam scanner as part of a small field dosimetry study. Uniform dose responses and small field depth doses revealed each sample was unique. As the gels aged over several weeks at 4 °C, the dose sensitivity decreased. Reconstructions of uniform dose distributions revealed unique features near the vessel interface. The central sub-volumes ranged from uniformity to within 2% throughout the sub-volume to a 12% gradient from base to top of gel. Comparisons of small field depth doses revealed that if the central volume had a uniform dose response, no correction was required. However, if a gradient in sensitivity from bottom to top was measured a correction may or may not be required. It is suspected that the filling protocol of the custom vessels is a factor in the observed variations in 3D dose response.

1. Introduction
In order to perform accurate 3D dosimetry the entire measurement protocol needs to be calibrated. This includes evaluating the dosimeter, vessel, readout scanner and data processing algorithms. During a study of motion effects on 3D small field dosimetry, repeat irradiations were conducted and the spatial uniformity of dose response is reported for a set of four samples.

ClearView™, a radiochromic hydrogel from ModusQA, was selected for this study because of its acceptable dose sensitivity at 20 Gy maximum dose, no diffusion and sufficient optical transmission for 15 cm diameter samples [1-3]. The experiments were refined over several irradiations conducted over a year and the later samples are the focus of this report. The experiment included four small field irradiations, consisting of a static gel as sample reference and 3 repeat irradiations with the gel moving. The cylindrical gel was irradiated through the flat base and each beam was delivered to a separate quadrant. This sequence provided an internal reference, the static beam, for each experiment. However, this approach assumes that each sample has a uniform dose response. In order to verify isotropic dose response, samples were irradiated with a uniform dose before or after the small field motion experiment.

2. Methods
ModusQA prepared the ClearView batches and filled the custom polyethylene terephthalate (PETE) vessels, constructed by one of the authors. These custom vessels have higher optical quality walls than the current blow-molded jars provided by ModusQA. However, the vessels have a much smaller hole for filling and had different heights compared to the blow-molded jars. This resulted in filling procedures...
that were different from those optimized by ModusQA for the jars. Optical CT scanning was performed with a Vista16 cone beam scanner provided by ModusQA. The scanner was modified, in-house, by placing a 15 mm diameter aperture at the source to minimize stray light [4]. Early scans, at 530 nm, were scaled for direct comparison with the later scans performed at 590 nm, based on the absorption spectrum. One thousand projections were acquired for both the reference and data scans with a 30 minute post irradiation delay for image development. Reconstructions were performed with iterative OSC-TV algorithm and default parameters, implemented by ModusQA in VistaScan program with 0.5x0.5x0.5 mm³ voxels. Central axis attenuation coefficients were averaged over 1.5x1.5x0.5 mm³ for figures 1 and 2. Monte Carlo calculations were performed with EGSnrc code and results agreed with measured depth doses for pinpoint ion chamber.

The samples were received within two days of preparation and stored at 5 °C in the dark until radiation. Samples were then warmed in a water bath for 4-6 hours and kept at 20 °C for the experiment. In this study samples are identified by radiation date. May14 was same sample as May2 but stored at 20 °C in dark since May 2nd experiment and was two months old. Sept16 (one week old) and Sept30 samples were from a later batch. Sept30 vessel was 15 cm diameter by 8 cm height with 0.5 mm polyethylene terephthalate glycol (PETG) ends and other vessels were 10 cm diameter by 12 cm height with flexible 0.25 mm thick PETE film ends. Vessel cylinder sides were constructed of the same 0.25 mm PETE film. Irradiations were performed with a Varian 2100 IX series linear accelerator; 6 MV, 600 MU/min. Small field irradiation details: gel base facing beam at 90 cm source to surface distance, jaw sizes 1.4x1.4 cm, 2642 MU per beam (~20 Gy at 50 mm depth). Uniform dose irradiation details: 10 Gy, sample in 20x20x20 cm water tank, gel center at 100 cm isocenter, 4-field delivery.

3. Results

Reconstructions of the uniform dose irradiations revealed the samples differed from each other in their dose response. Sub-volumes along the ends and cylinder walls showed local variations in reconstructed attenuation coefficients. For this reason, the outer 1 cm of gel is excluded from this study. The central volume showed radially uniform response to <5%. However, May14 sensitivity linearly increased ~12% from base to top, Sept16 linearly decreased ~12% from base to top, Sept30 was uniform <2% throughout volume and May2 did not receive a uniform dose. Note, Sept30 uniform dose experiment showed similar response in central volume but different spatial responses near perimeter compared to the same vessel filled with a previous batch. Indicating the vessel filling protocol has measurable impact, especially in sample perimeter. Reconstructions also reveal high contrast artifacts that are due to ‘short strings of solid gel’ dispersed throughout the samples.

Figure 1, is a plot of reconstructed attenuation coefficients for the static beam central axis from each experiment. Sept16 was the most sensitive and a decrease in sensitivity due to storage time was seen with Sept30 and May2 curves. May14 scan reveals dose sensitivity increased from May2 due to interim storage at 20 °C. From other data sets, sensitivity batch to batch is similar when comparing samples that have been in 4 °C storage for longer than a month. The hollow marker curves show attenuation coefficients corrected linearly from the base to the top for changes in sensitivity recorded for the Sept16 and May14 samples. No spatial correction was required for the Sept30 experiment and the May2 scan was plotted using the May14 correction for comparison. Note, the Sept30 vessel was shorter, providing less depth dose data. In figure 2, the curves are normalized to a depth of 50 mm, to minimize impact of spatial variations in sensitivity near the sample’s outer sides. The curves which have better agreement with Monte Carlo depth doses are uncorrected Sept30, Sept16 and corrected May14.
Figure 1. Plot of central axis attenuation coefficients versus slice #, solid line or markers. Correcting bottom to top change in sensitivity, open markers. Note, vessel height Sept30 8 cm and others 12 cm.

Figure 2. Plot of central axis attenuation coefficients vs Monte Carlo calculated depth doses. Curves normalized at a depth of 50 mm. Note May2corr curve generated with correction from May14 irradiation as a surrogate.
May2 corrected with May14 data is also presented. The Sept30 results demonstrate that 3D dosimetry is possible, but the Sept16 spatial response indicates that a correction should be applied. However, the comparison with Monte Carlo depth doses indicates no correction is required. The May14 result shows the opposite effect, namely a spatial correction is required to get agreement. While May2 corrected indicates May14 correction is applicable from top to 3 cm above base.

4. Discussion

ClearView™ gel has the potential for accurate 3D dosimetry as shown by agreement between Monte Carlo calculations and measured depth doses. However, early results with custom vessels show that each sample is unique and a correction for spatial variations in dose sensitivity are sometimes required. Further experimentation is required to identify the causes for these spatial variations and why corrections may or may not be required. Similar effects have not been reported with more aged samples in the Vista jars but decreases in sensitivity and spatial variations were observed previously during the first month [5]. It is anticipated that an optimized filling procedure for these custom vessels is needed to obtain reproducible 3D responses. Another potential factor is the custom vessels. The Sept30 vessel was constructed with 0.5 mm thick PETG ends vs the 0.25 mm PETE ends on the other vessels. The thicker ends provided stiffer vessels and limited flexing when filled with ClearView™. It had been observed that vessels with air head spaces could develop a layer of liquid on their surface and along the sides if tipped on side or upside down for irradiations through the base end. A liquid between the vessel wall and gel may have an impact of transmission images. ClearView™ gel does not adhere to PETE in contrast to gelatin hydrogels which bond to the plastic interface. It also appears to shrink slightly with aging and this could introduce an optical effect at the vessel wall. These differences may be a factor in reproducibility for the results presented here. Once this base to top gradient in dose response is minimized, smaller effects such as impact of aging and oxygen gradients can be identified and addressed.

5. Acknowledgments and Disclosures

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