Performance of latex balloons for optical computed tomography

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Abstract. Latex balloons filled with radiation sensitive hydrogels were evaluated as 3D dosimeters with optical computed tomography (CT) readout. Custom balloons, with less than 10 cm diameters, were made from latex sheets. Commercial, 13 cm diameter, clear balloons were investigated for larger volumes. Ferrous-xylenol orange and genipin gelatin gels selected for 1 and 30 Gy experiments, respectively. The thin stretched latex membrane allowed optical imaging to within 1 mm of the interior balloon edge. Reconstructed dose distributions demonstrated valid measurements to within 2 mm of the balloon surface. The rubber membrane provides a hybrid approach to deforming hydrogels. Uniform irradiation of a deformed gel resulted in a uniform dose being measured when scanned in the relaxed, initial balloon shape. The 13 cm diameter balloons were also effective and inexpensive vessels for hydrogels due to their high clarity, thinness and mechanical strength. Latex balloons represent an inexpensive method to obtain useful information from nearly the entire dosimeter volume.

1. Introduction
Optical computed tomography (CT) for 3D radiation dosimetry involves either radiation sensitive hydrogels or plastics. The hydrogels generally require a plastic sealed vessel to provide mechanical rigidity and chemical isolation. One important advantage of radiochromic plastics, such as Presage, is the elimination of the vessel and optical artifacts that are associated with refractive index mismatch between the gel and vessel wall. The optical artifacts include: reflections, refractions, internal wave-guiding in the wall and polarization effects. The exception is genipin hydrogel which has been optically scanned to the surface without support in a vessel [1]. FEP Teflon has a refractive index similar to hydrogel formulations and is used when dosimetry to edge of vessel is required. However, oxygen permeability is a limitation for some of the radiation chemistries under investigation. High refractive index plastics are also used for optical CT vessels and if the wall is thin enough most of the gel interior can be probed. This effect was characterized by Krstajic [2] and has important implications for optical CT design and performance. Latex balloons when stretched to near bursting become very transparent and are now being used for gel dosimetry with optical CT readout. Results with radiochromic gels and polymerization gels in latex balloons have been reported [3,4]. Because of the thin latex membrane surrounding the gel it is expected that optical sampling to the inner edge of the balloon should be possible. This feature increases the efficiency of 3D gel dosimetry by measuring dose throughout the entire dosimeter volume. The hybrid mechanical properties of the gels and balloon allow deformable dosimetry to be possible.
2. Methods

Initial tests indicated that commercial clear latex balloons were more scattering than latex sheet prepared in the laboratory without mould-release coatings. Latex sheets were prepared by pouring raw latex onto glass plates and annealing at 65°C for one day. Circles were cut from the sheet and attached to a custom fill tube. Ferrous-xylenol orange (FX) gel was injected into the tube to form balloons that ranged in diameters from 40 to 100 mm diameters. Commercial “5 inch clear” latex balloons were filled with genipin gel. Ferrous xylenol orange gels were prepared with 4% gelatin by mass, 50 mM sulfuric acid (H₂SO₄), 0.3 mM ferrous ammonium sulphate and 0.05 mM xylenol orange. Genipin gel was prepared with 3% gelatin by mass, genipin 0.1% mass of gelatin, and 200 mM H₂SO₄. The genipin and gelatin were dissolved in distilled water and stirred at 45°C for 18 hours and acid was added to form the stock gel. A stock gel sample was diluted with blank gel (200 mM H₂SO₄, 3% gelatin) to achieve acceptable level of transmission at 594 nm for optical CT scans.

The smaller FX gel-balloon was scanned by a modified Vista10 optical CBCT scanner (590 nm light, 512 projections per 360 degrees, camera lens aperture of F4 and 8 minute scan time) from Modus Medical Devices. Reconstruction with Vista software was performed at 0.25 mm³ voxel size with Ramp filter, generating a 512³ array of attenuation coefficients. While the larger, genipin gel – balloon was scanned with an in-house prototype laser scanning CBCT scanner (594 nm laser light, 512 projections per 360 degrees, 200 slices, 30 minutes scan time). Propylene glycol aqueous solutions were prepared for refractive index matching of the balloon phantoms. Reconstruction was performed with in-house software implementing the FDK algorithm with 0.34 mm³ voxel size, Ramp filter and 512x512x200 output array. A photograph of the phantom in the aquarium is shown in figure 1. A centering base ring was made for the balloon and fixed to the CT rotation platform. The liquid level was adjusted so that several centimeters of the balloon neck was above the liquid to provide sufficient friction between the gel and the rotation platform. A black, ink-spot fiducial was placed on the balloon. The laser beam was directed onto the fiducial and the position recorded. After irradiation the balloon was again placed in the scanner and adjusted until the fiducial aligned with the laser beam.

![Figure 1: Photograph of latex balloon filled with genipin hydrogel positioned in refractive index matched laser CBCT scanner. Note: laser beam aligned with black ink spot fiducial above liquid surface and reflection centered on optical axis.](image-url)

The gels were placed at isocentre of the radiotherapy machines in a 20x20x20 cm water phantom for irradiation. Parallel opposed beams 20x20 cm cross section delivered 1 and 30 Gy respectively to the FX and genipin balloons. The FX gel was deformed prior to irradiation to a uniform dose of 1 Gray and then allowed to relax before the data scan was obtained. A second irradiation was delivered to the genipin balloon, orthogonal, 5x5 cm, 10 MV beams of 15 Gray each at isocentre.
3. Results and Discussion
The optical performance of a small 5.5 cm diameter FX gel-filled latex balloon is shown in figure 2. The projection image was acquired with a modified Vista10 optical CBCT scanner. A transmission image through the gel and balloon was taken of a clear, plastic ruler placed at the entrance window to the aquarium. The 1 mm gradations on the ruler are clearly resolved, demonstrating the low optical scatter of this dosimeter.

![Figure 2](image)

**Figure 2:** Transmission image of plastic ruler placed between diffuse light source and a custom latex balloon filled with ferrous-xylenol orange gel mounted in a modified Vista10 CBCT scanner.

At the edge of the balloon all gradations can be counted and no distortion of the lines is observed. This demonstrates that light passing less than 1 mm from the edge of the balloon can be imaged. In figure 3, a reconstructed slice of a uniform dose distribution is shown demonstrating that quantitative dosimetry can be obtained to within 2 mm of the balloon edge with FX gels. Note the segment of the perimeter where the gel-balloon had not returned to its original, reference scan shape.

A genipin gel-filled commercial “5 inch clear” balloon, irradiated to a uniform dose of 30 Gray, was scanned with a prototype laser CBCT scanner. In figure 4, the reconstructed attenuation indicates a lower sensitivity towards the balloon dosimeter edge. Further experiments are required to verify this.

![Figure 3](image)

**Figure 3:** Central transverse slice from reconstruction of uniform 1 Gy dose, delivered to deformed balloon. Note, lower left perimeter where balloon shape had not completely relaxed.

![Figure 4](image)

**Figure 4:** Central slice following irradiation of dosimeter (figure 4) with crossed 10 MV photon beams. Balloon was centered in water phantom during irradiation.

![Figure 5](image)

**Figure 5:** Central slice following irradiation of dosimeter (figure 4) with crossed 10 MV photon beams. Balloon was centered in water phantom during irradiation.
result. Generally, non-uniform gel dosimeters can be improved by pre-irradiation with a uniform dose. Next the same balloon was with irradiated with orthogonal beams. The middle slice of the 3D reconstruction is shown in figure 5. The dose distribution is continuous to the edge of the dosimeter indicating that quantitative measurements to the edge of this dosimeter are possible. A similar conclusion with nPAG gel has been reported [4]. The dominant ring artifact is related to a reflection from the balloon.

4. Conclusion
Latex balloons provide a high efficiency vessel for optical CT scanning of hydrogels because of the thin rubber membrane. This allows optical sampling to within 2 mm of the balloon edge. Reconstructions are then useful to similar proximity of the dosimeter’s perimeter. Both ferrous-xylenol orange and genipin hydrogels in latex balloons were used to demonstrate that dose distributions could be measured to within 2 mm of edge. This optical and chemical performance allows nearly the entire gel to be used as a dosimeter. Hydrogels within latex balloons can be reversibly deformed without tearing. This allows handling of the gel filled balloons without damage to the dosimeter and provides a method to perform deformable 3D dosimetry.

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6. References
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