Effects of adding glycerol and sucrose to ferrous xylenol orange hydrogel

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Abstract. Glycerol and sucrose were substituted up to 40% by mass for water in ferrous xylenol gelatin hydrogel (FX). Both materials increased the refractive index of the aqueous component of the gels and lowered the optical scatter coefficient. Diffusion of the FX products was reduced 3-fold at 40% substitution levels. The radiation response was more stable with glycerol.

1. Introduction
Gelatin hydrogels such as ferrous xylenol orange (FX) that contain around 4% gelatin by mass are among the most transparent radiochromic materials available for 3D dosimetry with optical CT readout. Because the materials are relatively inexpensive, large volume dosimeters could be prepared with this material. Specifically, samples up to 30 cm in diameter may be useful for specialized dosimetry problems requiring complete sampling of large volumes. Optical cone beam CT can be modified in order to scan large volumes [1]. But with a diffuse source this geometry is more prone to stray light than other geometries such as single ray – single detector laser CT scanner geometries. Dosimeters that exhibit the least amount of scatter are expected to result in the greatest spatial resolution and most accurate reconstructed attenuation coefficients. It is anticipated that radiosensitive gels with higher scatter will have inferior optical performance when scanned with cone beam optical CT systems [2].

One approach to stray light reduction in transmission images through this hydrogel is to add chemicals that increase the effective refractive index of the aqueous component of the gel [3]. The effect of adding glycerol to FX gelatin hydrogel was reported earlier [4]. In this study sucrose and glycerol were compared for scatter reduction in FX gelatin hydrogels. Other dosimeter parameters examined were: dose sensitivity, auto-oxidation and diffusion rates.

2. Methods
Reference FX gelatin hydrogels contained: 4% by mass gelatin (porcine, type A, 300 Bloom), 0.3 mM ferrous ions, 0.05 mM xylenol orange and 50 mM sulphuric acid. Sucrose or glycerol was substituted for fractions of the water during gel preparation. They were added after the gelatin was dissolved in water at 40°C. All materials except the sucrose were from Sigma-Aldrich. The sucrose was purchased as coarse granulated cane sugar locally. The glycerol was pre-treated to scavenge oxidizing species by adding zinc metal pellets and stirring for several minutes. Samples were prepared with dopant concentrations ranging up to 40% by mass. Above this level the materials were
very viscous and difficult to pour as optically uniform samples. Gelatin hydrogels doped with 50 mM 
H$_2$SO$_4$, 30% glycerol or 40% sucrose were placed in 10 cm pathlength custom plastic cuvettes for 
scatter measurements.

Attenuation spectra were recorded from 400 to 700 nm with a Perkin Elmer model 139 UV-VIS spectrometer. Dose response measurements were performed on single one cm pathlength PPMA 
cuvettes with sequential irradiations. Transmission measurements were performed at 30 to 32 minutes 
postirradiation. A Varian 600C medical accelerator (4 MV photon beam) was used for irradiations. 
The diffusion experiment included, irradiating half of a 1 cm cuvette sample to 5 Gy and recording 
sequential transmission images over several hours at 590 nm with an in-house optical cone beam 
scanner. The spatial resolution was 12 pixels per mm. Profiles from the sequence of images were fit 
to calculate a linear diffusion coefficient [5].

3. Results and discussion
Increasing the hydrogel gelatin content from 4% to 8% effectively doubled the scatter coefficient at all 
visible wavelengths. Approximately a 30% reduction in scatter was obtained by substituting 30% 
glycerol or 40% sucrose for water in the hydrogels.

The FX gels became stiffer, were darker orange and had increased auto-oxidation rates as a 
result of increased doping levels. The profiles at 0.5 and 4.5 hours post irradiation for gels with 40% 
sucrose or glycerol are shown in figure 1 with offsets to correct for auto-oxidation. Note that the 
radiochromic response of the sucrose sample continued to increase after 0.5 hours but the glycerol gel 
response was stable. This longer development time with sucrose is problematic for reproducible 
measurements.

![Post irradiation attenuation profiles for FX gels: 40% sucrose (0.5(□), 4.5(■) hours), 40% 
glycerol (0.5(○), 4.5(●) hours). Right half received 5 Gy. See text concerning long development time 
with sucrose.](image)
Profiles were recorded from 0.5 to 5 hours after irradiation in 0.5 hour intervals. The fitted data resulted in measured diffusion coefficients of 0.145 and 0.175 mm$^2$ hr$^{-1}$ for 40% sucrose and glycerol gels respectively. These values are three times lower than the 0% reference FX gel. Note that earlier work with 10% gelatin gels would have predicted negligible reduction in diffusion rates [6]. Also, glycerol has been reported to increase dose response at low concentrations and decrease response at high levels in Fricke solutions [7]. Sucrose follows a similar trend of increasing dose sensitivity at low concentrations [8] and decreasing sensitivity at higher levels in FX gelatin hydrogels, this work.

4. Summary
The addition of either sucrose or glycerol lowered scatter in FX gels. However, minimizing gelatin content was a more significant parameter. Both additives lowered diffusion to a similar degree. However, the post irradiation signal from the sucrose gel samples continued to increase for several hours. Sucrose is optically active and may introduce nuisance, polarization artifacts for optical scanning [9]. Since, glycerol lowered both scatter and diffusion while stiffening the gel it should be considered as useful method to improve optical performance when scanning larger gel volumes and for experiments that require a lower diffusion rate. It is recommended that 4% gelatin and 30% glycerol be used when minimal scatter FX gel is required.

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