Three-Dimensional Dose Verification Using an Optimized Fricke Xylenol Orange Gel With Optical CT and MRI

G S Lee[1], K M Alexander[1,2,3], and JD Jutras[1,4]

[1] Department of Physics and Astronomy, University of Calgary, Calgary, Alberta, Canada
[2] Department of Oncology, Queen's University, Kingston, Ontario, Canada
[3] Medical Physics Department, Cancer Centre of Southeastern Ontario at Kingston Health Sciences Centre, Kingston, Ontario, Canada
[4] Department of Medical Physics, Arthur JE Child Comprehensive Cancer Centre, Calgary, Alberta, Canada

Introduction

Fricke Gel Dosimetry

Dose quantified by NMR through radiation-induced $Fe^{2+} \rightarrow Fe^{3+}$ oxidation.[1]

Optical CT Adoption

Early MRI limitations and the introduction of xylenol orange (XO) made optical CT more practical and widely adopted.[2, 3]

Renewed MR Interest

Advances in MRI and MR-guided radiation therapy renewed interest in MR-based Fricke gel dosimetry.

Can an optimized FXO gel support MR-based 3D dose readout while maintaining compatibility with optical CT?

Methods

1 Fabrication

- FAS (0.15–1.0 mM) and XO (0.01–0.10 mM) varied to maximize dose sensitivity while minimizing auto-oxidation and diffusion.
- Optimized formulation: 0.42 mM FAS, 0.05 mM XO, 65 mM H_2SO_4, and 6.3 wt% gelatin

2 Irradiation

- Treatment jars irradiated in an in-house cylindrical phantom using a Varian TrueBeam.
- Liver SBRT and brain SRS plans scaled to 3 Gy and 4.5 Gy to remain below optical CT saturation.
- Calibration jars irradiated with a 12 MeV electron beam using a 4 cm cutout at 100 cm SSD.

3 Readout

- Jars imaged before and 30 minutes after irradiation.
- 3D R1 maps generated using MP2RAGE.
- 3D optical attenuation (OA) maps reconstructed using FDK.
- Both acquired at 0.5 mm isotropic resolution.

4 Dose Calibration

- ΔR1 and OA profiles from the calibration jar aligned to a 12 MeV PDD measured with a microDiamond detector.
- Both linearly fitted as a function of dose to generate calibration curves.

5 Dose Comparison

- Calibrated MR- and optical CT-based dose distributions compared with the treatment planning dose.
- 3D gamma analysis and line profiles using the gel dosimetry workflow in 3D Slicer.

a) Treatment jar setup b) Calibration jar setup c) Post brain SRS plan d) Post calibration dose

Figure 1. *Irradiation setup and radiation-induced colour change 30 minutes after delivery.*

Acquisition & Analysis Parameters
MRI scanner/field: 3 T Siemens MAGNETOM Vida
Optical CT scanner: Modus QA Vista 16
Gel-TPS registration: Fiducial-based registration
Calibration range/fit: 0–6 Gy, linear (R^2 = 0.9996)
Gamma criteria: 2%/2 mm liver; 3%/1 mm brain

Results

- Mean PTV doses agreed with the treatment planning dose within 2.84% for liver SBRT and 4.87% for brain SRS using MR readout, comparable to optical CT at 1.93% and 4.87%, respectively (Table 1).
- All measured mean doses within 1σ of the corresponding treatment planning dose.
- Gamma pass rates measured at 89.9%–97.9% across both readouts and treatment plans.
- MR-based dose distributions noisier than optical CT but still showed good agreement with the treatment planning dose distributions (Figure 2).

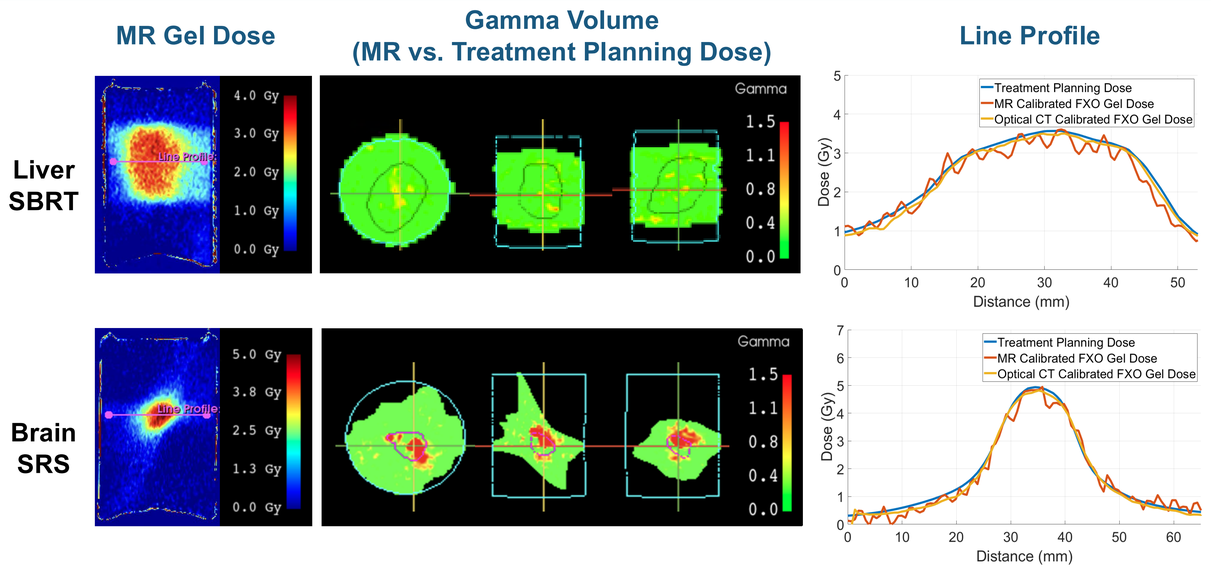

Figure 2. *MR-based calibrated gel dose distribution, gamma volume, and line profile for each clinical plan. Profiles compare MRI, optical CT, and treatment planning dose.*

Clinical Plan	Readout Method	Mean Dose Inside PTV			Gamma Pass Rate (%)	Gamma Criteria
		Treatment Planning Dose ($\mu \pm \sigma$, Gy)	Gel Measured Dose ($\mu \pm \sigma$, Gy)	% Difference		
Liver SBRT	MR	3.22±0.23	3.13±0.30	2.84	96.9	2%/2 mm
	Optical CT		3.16±0.22	1.93	97.9	
Brain SRS	MR	4.17±0.47	3.97±0.59	4.87	91.7	3%/1 mm
	Optical CT		3.97±0.50	4.87	89.9	

Table 1. *Comparison of MR- and optical CT-based gel dose measurements with the treatment planning dose (μ = mean, σ = standard deviation), showing mean dose difference and gamma pass rates.*

Discussion & Conclusion

- Same optimized gel formulation and treatment plans used to enable a direct comparison of MR and optical CT readouts against the reference treatment planning dose.
- MR noise attributed to the acquisition time trade-off between improving SNR and limiting diffusion.
- Both clinical plans scaled down because of optical CT saturation; MR readout not subject to the same saturation limit, providing an advantage for clinical SBRT and SRS prescription doses.
- Inter-batch reproducibility required before a measurement uncertainty can be determined.

We developed an MR-optimized FXO gel formulation that supports quantitative 3D dose readout. Future work will focus on clinical implementation of FXO gel dosimetry in MR-guided radiation therapy.

Contact Information

sieun.lee@ucalgary.ca

More Info

Please scan to read the full abstract

References

1. Gore JC and Kang YS. Measurement of radiation dose distributions by nuclear magnetic resonance (NMR) imaging. Phys. Med. Biol. 1984;29(10):1189-1197.
2. Olding T, Holmes O, Schreiner LJ. Cone beam optical computed tomography for gel dosimetry I: scanner characterization. Phys. Med. Biol. 2010;55(10):2819-2840.
3. Davies JB and Baldock C. Sensitivity and stability of the Fricke–gelatin–xylenol orange gel dosimeter. Radiat. Phys. Chem. 2008;77(6):690-696.