Optimized Polymer Gel Dosimetry for Kilovoltage X-ray Irradiations and 3D Isocenter Verification

Olivia Moluchi[1], Olivia Masella[1], Jade Fischer[1], Devon Richtsmeier[2], Joshua Chapman[1], Laura Dufort-Gagnon[1], Magdalena Bazalova-Carter[1]
[1]University of Victoria, [2]BC Cancer – Victoria

Introduction

- Accurate dose verification is essential for precise treatment delivery and patient safety.
- 3D polymer gel dosimeters (PGDs) enable the verification of volumetric dose distributions.
- Radiation-induced polymerization is proportional to absorbed dose[1].
- PGDs can quantify geometric offsets caused by gantry, couch, and collimator rotations that reduce dose conformity.

The purpose of this study was to optimize a NIPAM-based PGD for kilovoltage x-ray irradiations, and to demonstrate its application for 3D isocenter verification.

Materials and Methods

- Six formulations with varying BIS, NIPAM, and THPC concentrations were evaluated to optimize the PGD based on dose sensitivity, optical clarity, and manufacturing cost.

Table 1. Chemical compositions of PGD formulations.

	Formula					
Chemicals	**a**	**b**	**c**	**d**	**e**	**f**
Deionized (DI) Water	75.5%	75.5%	79.0%	81.0%	87.0%	84.0%
Gelatin	5.0%	5.0%	5.0%	5.0%	5.0%	5.0%
N,N'-Methylenenbis(acrylamide) (BIS)	4.5%	4.5%	8.0%	5.0%	3.0%	4.0%
N-Isopropylacrylamide (NIPAM)	15.0%	15.0%	8.0%	9.0%	5.0%	7.0%
Tetrakis(hydroxymethyl)phosphonium chloride (THPC)	10mM	5mM	10mM	10mM	10mM	10mM

- The optimized PGD was calibrated with a 225kVp beam on a dual-robot radiotherapy system (**KOALA**) and irradiated using 5mm diameter beams.
- EBT4 films were used for dose cross-calibration.

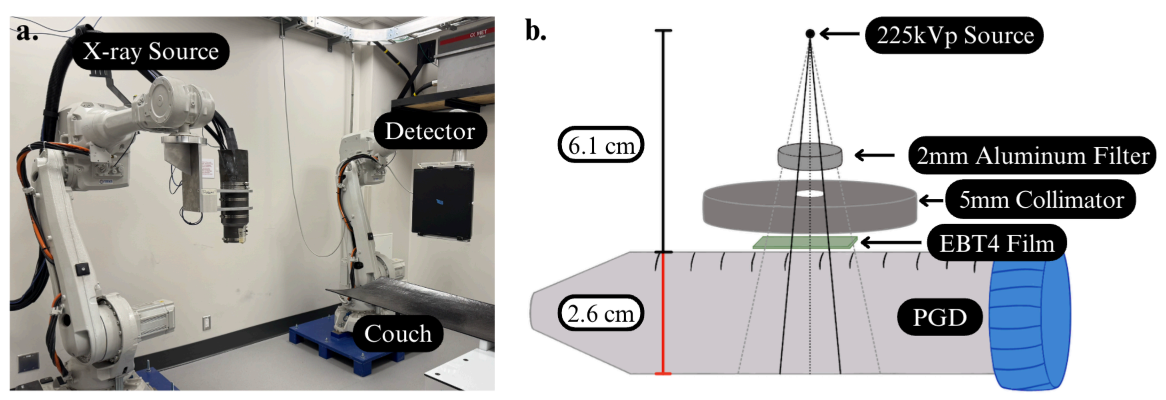

Figure 1. (a) KOALA and **(b)** a schematic of calibration irradiation.

- The PGD was imaged using a GE Revolution CT scanner, and 10 scans were averaged and background-subtracted.
- The resulting change in CT number (ΔN_{CT}) was measured within a 2×2mm^2 ROI over a 5-10mm depth range.
- ΔN_{CT} values were correlated with film-scaled TOPAS Monte Carlo (MC) simulated doses for calibration[2].

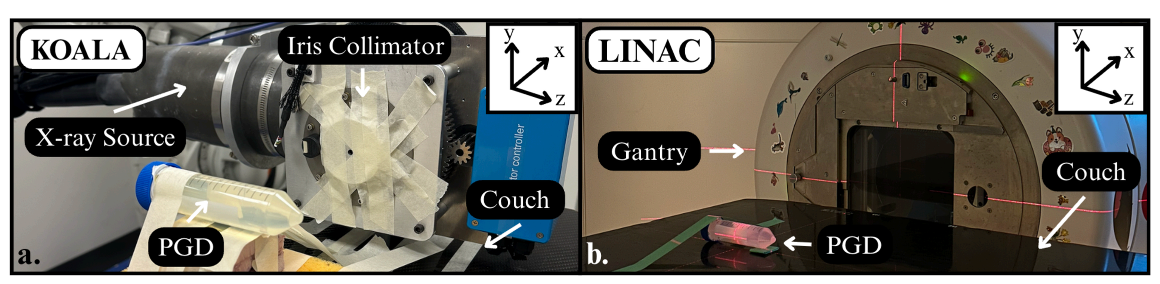

Figure 2. 3D star shot set-up for **(a)** KOALA and **(b)** LINAC.

- A 6-beam non-coplanar star shot was further performed on the optimized PGD using KOALA (225kVp) and a LINAC (6MV).

Results

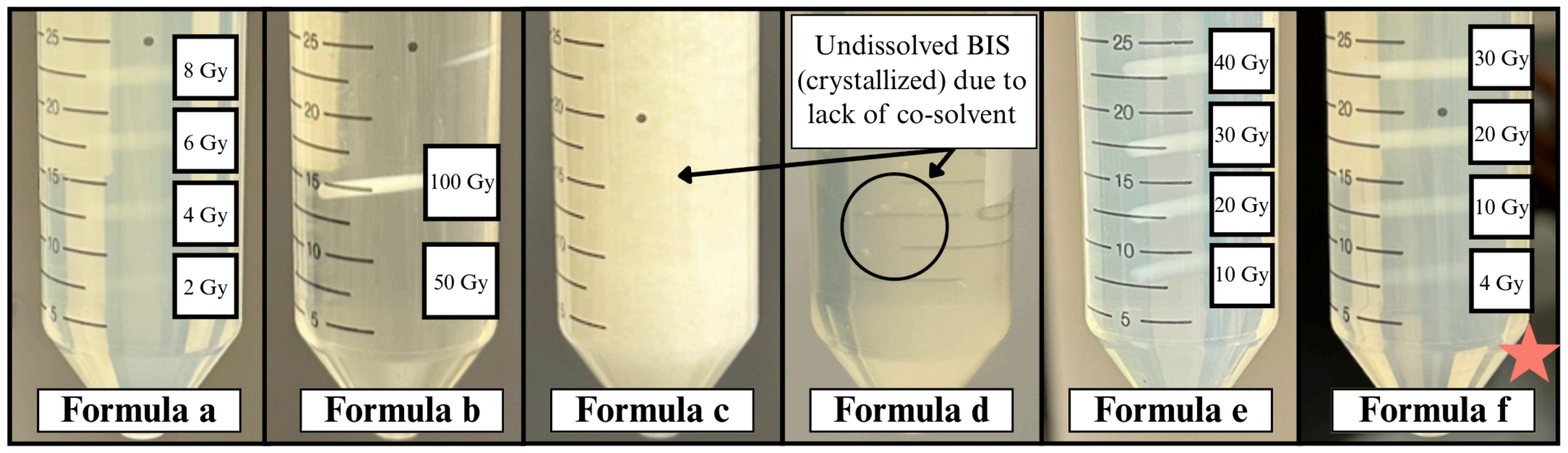

Figure 3. PGD sensitivity study formulations with varying chemical concentrations **(Formula a - f). (c)** and **(d)** show non-uniformities in the PGD due to limited solubility of BIS in the gelatin matrix. **(f)** Demonstrates the optimized formula.

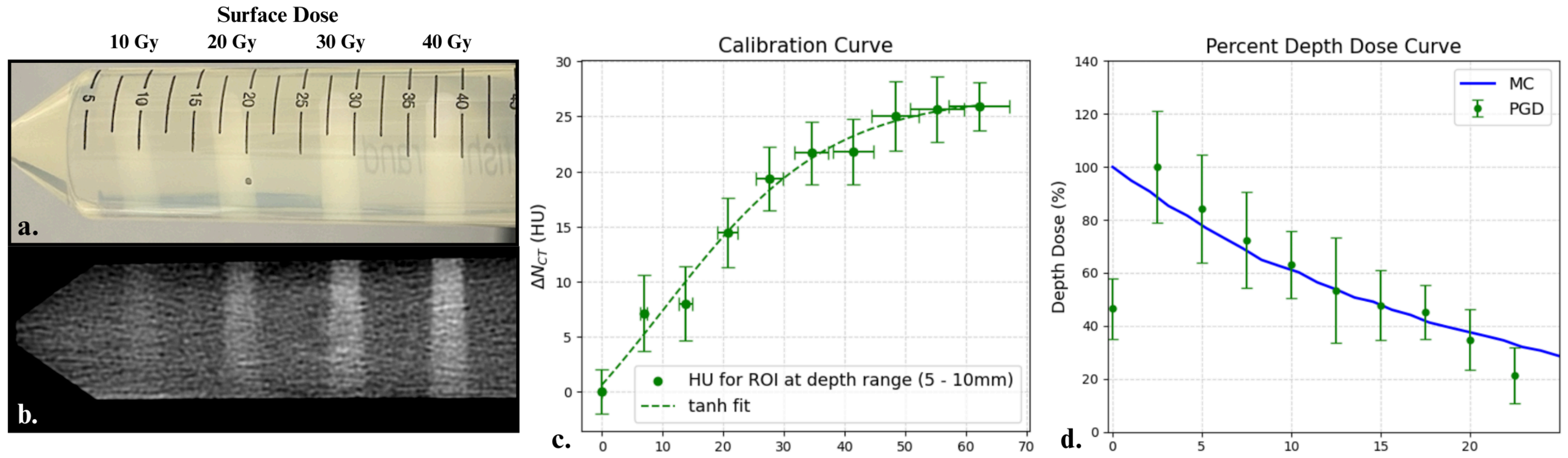

Figure 4. (a) Photo of one calibration PGD. **(b)** Averaged CT image of calibration PGD. **(c)** Dose calibration curve of the optimized PGD for KOALA 225kVp beam. **(d)** PGD-measured and MC-simulated PDD.

- Good agreement was shown between the PGD and MC-simulated PDD with a steep dose fall-off, resulting in ~70% of the dose administered in the ROI depth range.
- The optimized PGD had a non-linear dose response with a mid-range sensitivity of 0.6 HU/Gy.
- PGD saturation was observed at approximately 55 Gy.

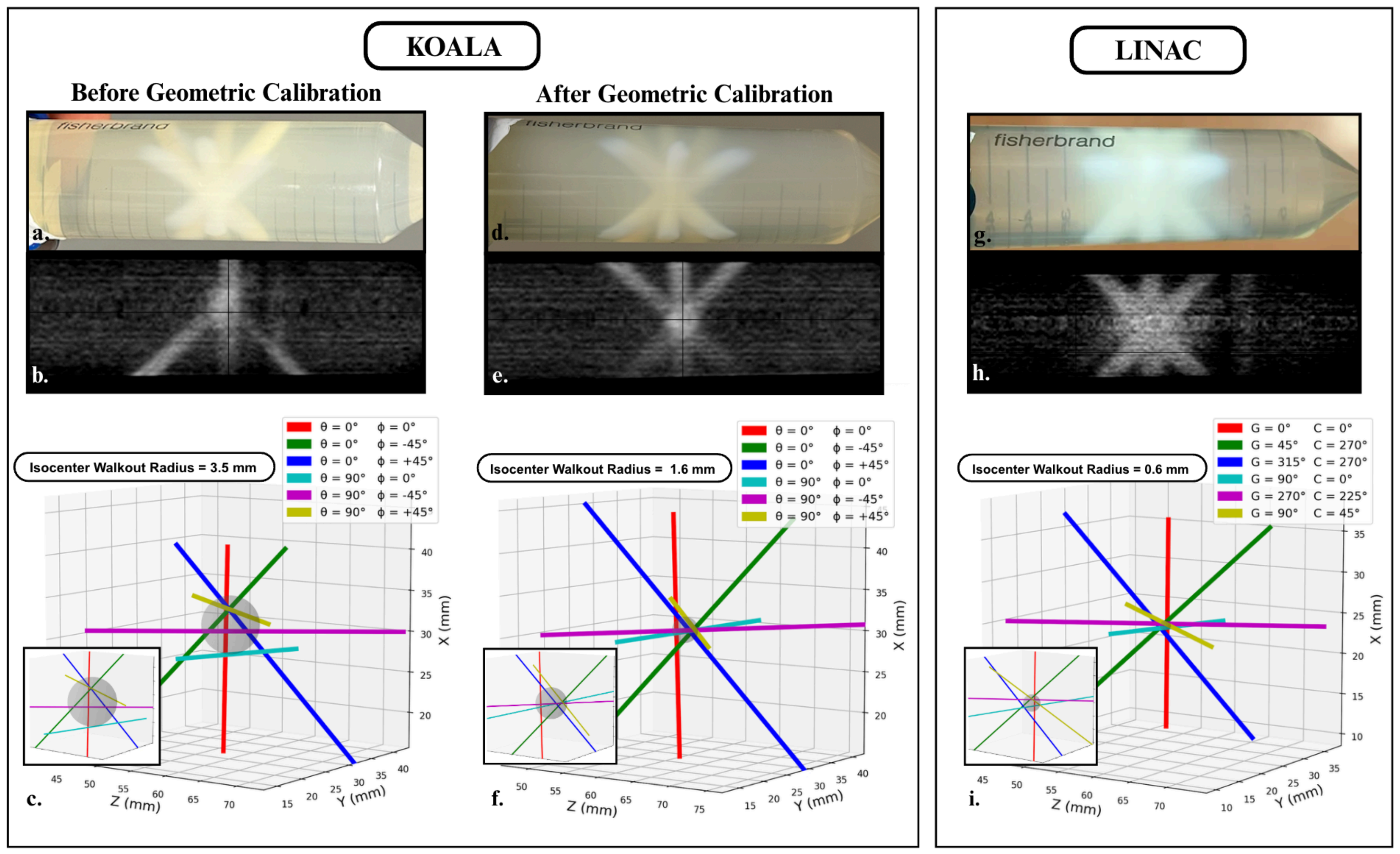

Figure 5. 3D non-coplanar star shot using the optimized PGD on KOALA **(a – f)** and a LINAC **(g – i)**. Averaged CT images before **(b)** and after **(e)** KOALA calibration, and for the LINAC **(h)**. Isocenter walkout analysis is shown for KOALA **(c, f)** and the LINAC **(i)**, where θ and ϕ denote x-ray source rotation and tilt, and G and C denote gantry and collimator rotations.

Conclusions

- A formula with 4% BIS, 7% NIPAM, and 10mM THPC was found optimal for high dose sensitivity of a 225kVp beam.
- Concentrations of BIS > 5% resulted in crystallization, decreasing the optical clarity of the PGD.
- Dose response of the calibrated PGD was non-linear for a range of 0 – 62 Gy with saturation occurring at ~55 Gy.
- A reduction in the KOALA isocenter walkout radius from 3.5mm to 1.6mm was achieved following a geometric calibration adjustment of the robotic delivery system.
- Isocenter walkout radius was quantified to be 0.6mm for the clinical LINAC.
- The production of high-energy secondary electrons from the 6MV beam on the LINAC caused a blurring of the irradiated beam edges.

Future Work

- Mini-beam SFRT in small and large phantoms of the optimized PGD.
- Clinical applications in breast radiotherapy, such as tissue-equivalent bolus and evaluation of motion effects during SFRT treatment.

References

[1] A. Jirasek, M. Hilts, and K. B. McAuley, "Polymer gel dosimeters with enhanced sensitivity for use in x-ray CT polymer gel dosimetry," *Physics in Medicine and Biology*, vol. 55, pp. 5269-5281, Sept. 2010.
[2] J. Perl, J. Shin, J. Schümann, B. Faddegon, and H. Paganetti, "TOPAS: An innovative proton Monte Carlo platform for research and clinical applications," *Medical Physics*, vol. 39, pp. 6818-6837, Nov. 2012.

Acknowledgements

The authors would like to acknowledge funding from the NSERC Discovery Grants and the Canada Research Chairs program. Additionally, this research was enabled in part by support provided by BC DRI Group and the Digital Research Alliance of Canada (*alliancecan.ca*).

Contact Information

Olivia Moluchi, University of Victoria
Email: omoluchi@uvic.ca