A Quantitative Evaluation of a Calibration Phantom for CT-based Dosimetry following Yttrium-90 Radioembolization

Courtney Henry[1,2], Aravind Arepally[3], Cheenu Kappadath[4], Alasdair Syme[1,2]
1. Nova Scotia Health, 2. Dalhousie University, 3. ABK Biomedical Inc., 4. M.D. Anderson Cancer Center

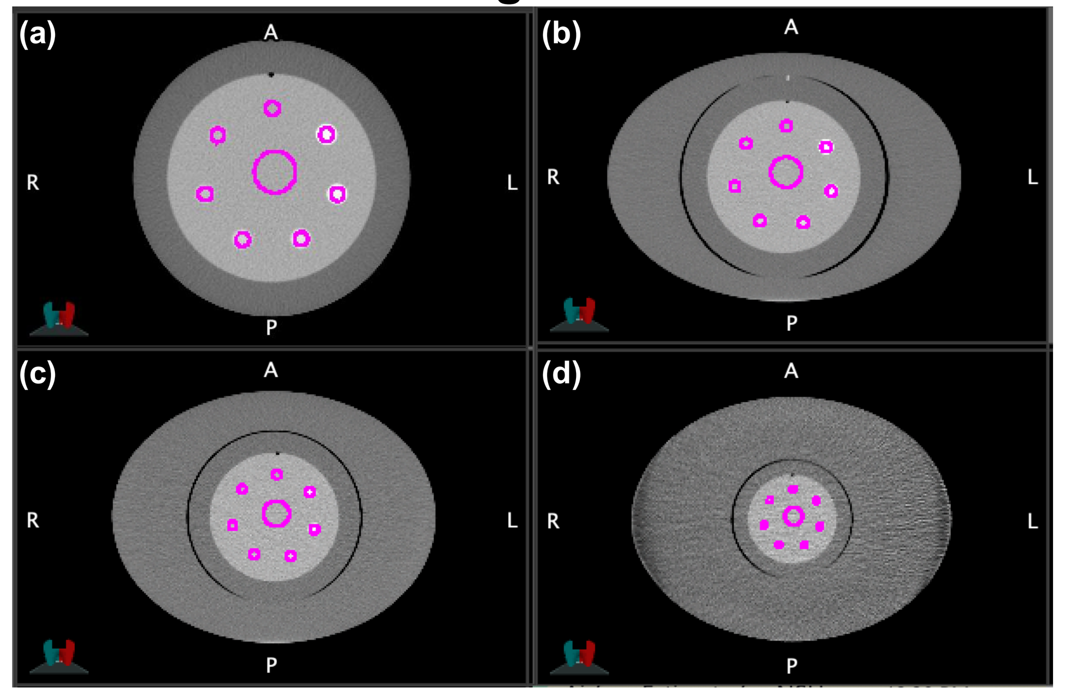
BACKGROUND

- Following yttrium-90 radioembolization (90Y-RE), a patient's absorbed dose can be measured through SPECT or PET imaging. While these dose distributions provide can reasonably reliable estimates of the mean dose at a macroscopic level, their utility in relating dose to patient outcome is associated with large uncertainties.[1]
- Radiopaque 90Y microspheres are readily visible using CT imaging.[2] However, an essential prerequisite for CT-based dosimetry following 90Y-RE is an understanding of the relationship between Hounsfield units (HU) and radiopaque microsphere concentration.
- To that end, a calibration phantom was designed for clinical implementation. The correlation between HU and microsphere concentration was evaluated. Microsphere detectability limits, concentration uniformity, and phantom fabrication reproducibility were also investigated.

METHODS

- The calibration phantom (**Figure 1a**) contains seven posts embedded in a tissue-equivalent. The posts have microsphere concentrations of 1, 3, 5, 7, 10, 15, and 25 mg/mL.
- Calibration phantoms were imaged using three X-ray tube potentials (100, 120, 140 kVp) and three external scattering annuli (small, medium, large) to simulate variability in patient size (**Figure 1b-d**).

Figure 1

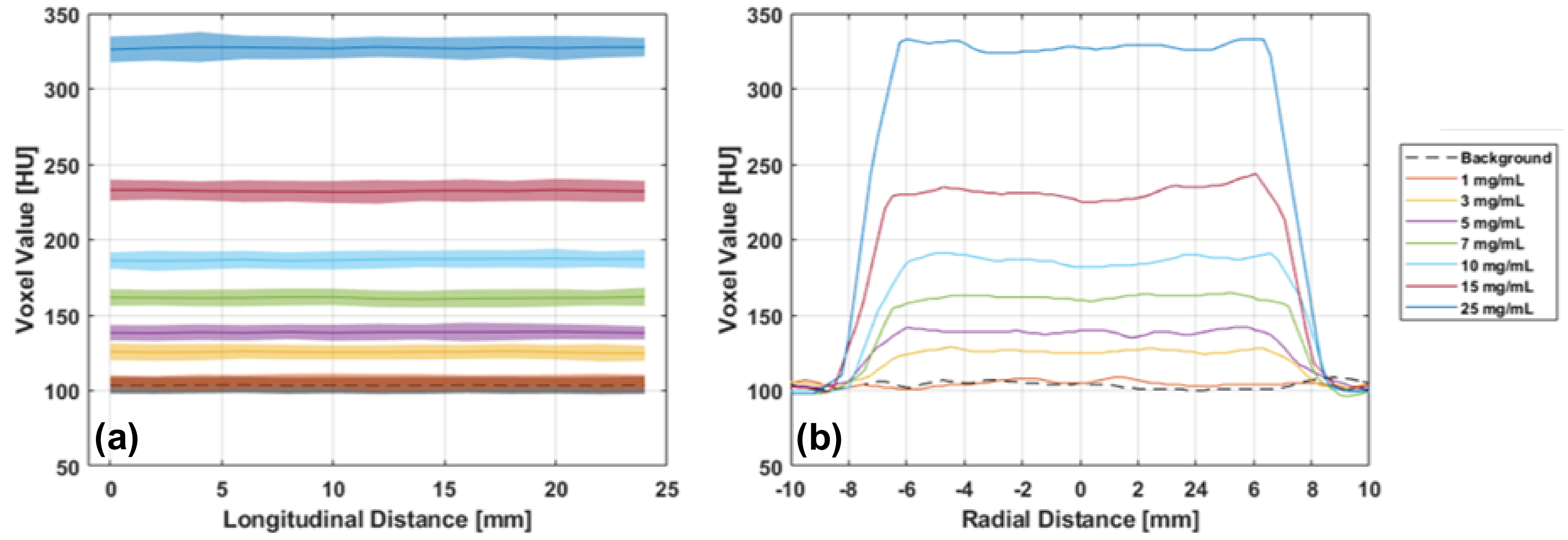


- The mean HU was extracted from posts and calibration curves were generated through linear least-squares fitting of the HU and microsphere concentration data. Calibration curve slopes m_{cal} were compared through an ANCOVA F-test.
- Microsphere concentration uniformity was determined using radial and axial HU line profiles while phantom reproducibility was evaluated through ANOVA. A statistical formalism was implemented to establish microsphere concentration limits of quantification: $LOQ_{mg/mL} = 3.29\sigma$, where σ is the standard deviation of HU in the lowest concentration post.

RESULTS

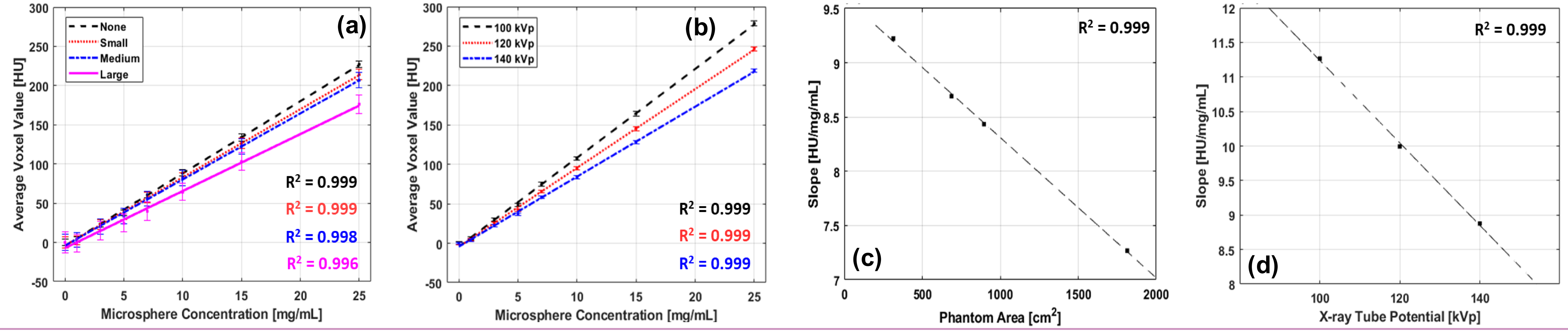
- Microsphere concentration is statistically independent across all posts (**Figure 2a**). A standard deviation ≤4.0 HU along radial line profiles indicates strong microsphere concentration uniformity in each post (**Figure 2b**). Phantom reproducibility was robust given the mean HU across identical posts differed by ≤2.5 HU. For a false positive rate of 5%, the median (range) of $LOQ_{mg/mL}$ across all CT scans was 3.51 (1.01 – 11.16) mg/mL, depending on X-ray tube potential and phantom size.

Figure 2



- Phantom size (p = 0.008) and X-ray tube potential (p = 0.001) significantly reduced m_{cal} (**Figure 3a-b**). The slope decreased by 1.29 x 10^{-3} HU/mg/mL per cm^2 of phantom cross-sectional area (**Figure 3c**), and by 5.97 x 10^{-2} HU/mg/mL per kVp (**Figure 3d**).

Figure 3



CONCLUSIONS

- The clinical calibration phantom has properties that are well-suited to the needs of CT-based dosimetry in 90Y-RE following the administration of radiopaque microspheres.
- Calibration curves should be generated individually for each patient and X-ray tube potential.

REFERENCES

1. Roosen, et al. *European Journal of Nuclear Medicine and Molecular Imaging* 48.12 (2021): 3776-3790.
2. Henry, et al. *EJNMMI Physics* 9.1 (2022): 21.