Improving the Accuracy and Detectability of HafO2 Nanoparticles

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INTRODUCTION

High–atomic number hafnium oxide ($HafO_2$) nanoparticles have demonstrated potential as radio-enhancers, but their detectability using standard CT calibration is limited. This work aims to (1) establish CT calibration curves for $HafO_2$ solutions of known concentration and (2) evaluate dual-energy CT's capability to improve the minimum detectable concentration of standard CT.

METHODS

RMI (Gammex) phantom inserts held aqueous $HafO_2$ solutions, 0.1% to 10% by weight, imaged with a thoracic free-breathing protocol (120 kVp) and dual-energy (100/140 kVp Sn) with monoenergetic and kVp reconstructions. A water-filled-vial scan served as control.

Circular ROIs (6 mm radius) were centered in the upper vial liquid, above any settled material, and averaged over the central liquid slices. Solid-water regions gave the water-equivalent reference and noise.

RESULTS

In thoracic free-breathing images (120 kVp), mean HU increased monotonically with concentration, from 36.2 ± 25.5 HU at 0.1% to 2,750.5 ± 138.8 HU at 10% by weight.

Dual-energy monoenergetic images increased contrast per unit concentration; 50 keV VMIs read 33.6 ± 26.5 HU at 0.1% and 4,131.4 ± 127.6 HU at 10%. Across reconstructions, 0.5% was clearly detectable (CNR > 5) while 0.1% approached the noise floor (CNR ≈ 1 to 2.5). Lower-energy VMIs gave the highest CNR.

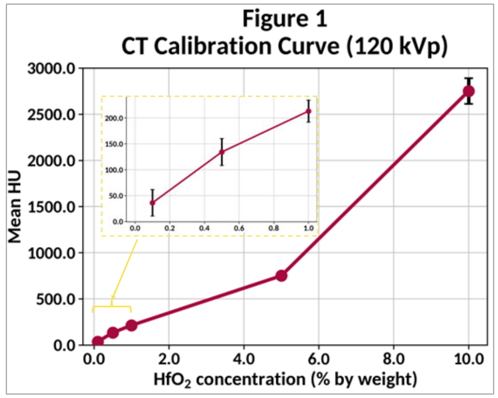

Figure 1. CT calibration curve at 120 kVp (thoracic free-breathing) for $HafO_2$ nanoparticle solutions. Mean HU increases with concentration from 0.1% to 10% by weight. Error bars represent ±1 SD (within-ROI noise).

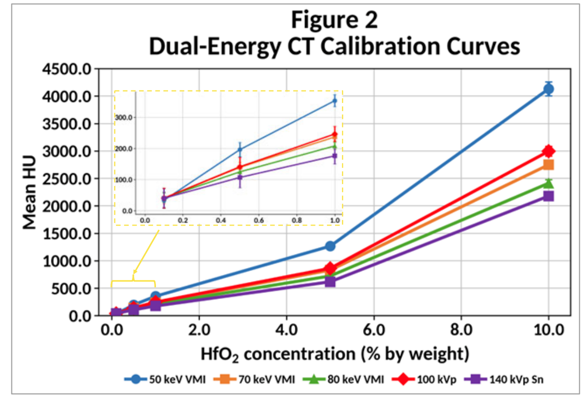

Figure 2. Dual-energy CT calibration curves for $HafO_2$ solutions: virtual monoenergetic images at 50, 70, and 80 keV, plus 100 kVp and 140 kVp (Sn) reconstructions. Lower-energy VMIs give the greatest contrast per unit concentration. Error bars represent ±1 SD.

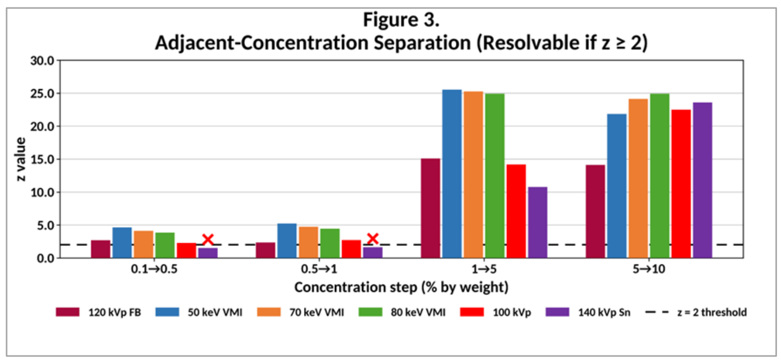

Figure 3. Adjacent-concentration separability by reconstruction. Bars represent the separation index z = |ΔHU| / √(SD_low² + SD_high²) between successive concentrations. Values above the dashed line (z ≥ 2, ~ 2σ) are statistically resolvable, and the red "x" symbols flag reconstructions that fall below it for a given step.

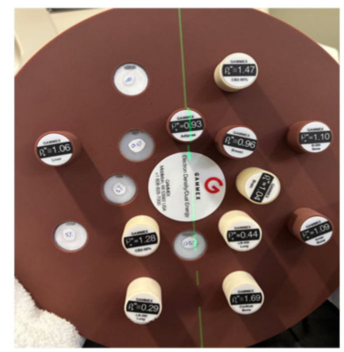

Figure 4. RMI phantom with inserts and vials containing HafO solutions of various concentrations.

CONCLUSIONS

- CT calibration curves for HfO_2 nanoparticles were successfully established and validated using a water-filled controls
- Dual-energy CT improved contrast per unit concentration compared with conventional 120 kVp CT.
- Low-energy virtual monoenergetic images provided the greatest contrast enhancement while maintaining image noise.
- HfO_2 concentrations ≥0.5% by weight were clearly detectable, while 0.1% approached the detection limit.

These findings support the use of dual-energy CT for improved visualization of HfO_2 nanoparticles in radiotherapy applications.

INNOVATION

To the best of our knowledge, this is the first attempt to calibrate HafO2 nanoparticle using clinical CT scanner.

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