Raw-data Effective Atomic Number (Z_{eff}) and Electron Density Assessment: A Phantom Study

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INTRODUCTION

With the advent of Dual Energy CT (DECT), measurements of Z_{eff} and ρ_e are now possible and bring with them a new level of diagnostic information. The applications of this information are wide ranging with uses in both radiology and radiation oncology.

AIM

To assess and quantify the accuracy and consistency of Z_{eff} and ρ_e measurements acquired from DECT acquisitions on a Canon Aquilion One Genesis DECT scanner using Canon Medical Systems' Z_{eff} and ρ_e measuring software (*Effective Z and Electron Density*, version 8; not FDA-approved).

METHOD

The Gammex Multi-energy head and body phantom was used to measure the Z_{eff} and ρ_e of 35 different rod inserts. Scans were performed using the default dual-energy head and bone edema protocols for the head and body phantom, respectively. Theoretical Z_{eff} of the rods were calculated using Mayneord's equation:[1]

$$Z_{eff} = \sqrt[n]{\sum_i \alpha_i Z_i^n} \qquad Eq. 1$$

This equation depends on an energy-dependent parameter *n*. A literature review found that the most common value for *n* is 2.94.[2-5] The electron density of the rods was provided by the manufacturer and were normalized to water. The percent errors of Z_{eff} and ρ_e measurements were calculated for each rod and the mean absolute percent error (MAPE) was reported for measurements in the head and body phantom for both Z_{eff} and ρ_e measurements.

Sources of variance were separated and quantified for measurements in the head phantom. Total variance was separated into three sources

1. Variance between multiple measurements within a single scan due to ROI position within the phantom
   - Estimated from measurements of solid water background
2. Variance between measurements done on repeated scans due to random photon statistics
   - Estimated from variance between rod measurements in consecutive scans
3. Variance between scans spread over time due to changes in the x-ray tube, calibration, and phantom position
   - Calculated by subtracting the two above sources of variance from the measured total variance

Only the total and first source of variance were measured in the body phantom.

The effect of positioning on the Z_{eff} and ρ_e measurements was tested by offsetting the phantom from center within the gantry and by taking measurements over all slices in the volumetric scan.

RESULTS

- All measurements showed high correlation (r > 0.98) with calculated theoretical values.
  - Accuracy results show in Table 1
- Measurements of the solid water background were found to vary significantly (p<0.001) depending on ROI position within the phantom
- Separation of variance results shown in Table 2 indicate that rod position within the phantom was the largest source of variance
- In the body phantom, the total average SD for Z_{eff} and ρ_e was 0.141 and 0.010, respectively. The SD due to ROI position alone was 0.135 for Z_{eff} and 0.0054 for ρ_e
- Z_{eff} measurements systematically decreased when the phantom was off-centered in the gantry, with the effect being more immediate in the lateral direction (Fig 2), while ρ_e measurements remained consistent
- Z_{eff} and ρ_e measurements remained within 2% and 0.5% of the central slice measurements over a range of 50-60 mm from the central slice, respectively
- Measurements showed a systematic bias that differed between the head and body phantom, shown in the Bland-Altman plots in Fig 1, indicating that bias of the software is dependent on phantom / patient size
  - Table 3 shows the results when measurements are corrected for bias through simple calibration

Table 1. Results for Z_{eff} and ρ_e measurements in the body and head phantom

		Z_{eff}	Electron Density
Body	MAPE	6.3%	4.6%
	Interval of Agreement	11.4%	7.9%
Head	MAPE	3.2%	1.0%
	Interval of Agreement	5.3%	5.2%

Table 2. Separation of variance results for head phantom

	Z_{eff}	Electron Density
σ_{photon}	0.009	0.0005
σ_{time}	0.013	0.0012
$\sigma_{position}$	0.046	0.0021
σ_{Total}	0.049	0.0026

Table 3. Bias-corrected results for Z_{eff} and ρ_e measurements in the body and head phantom

		Z_{eff}	Electron density
Body	Bias	-0.58	0.051
	MAPE	1.7%	1.5%
Head	Bias	0.28	0.003
	MAPE	1.2%	0.9%

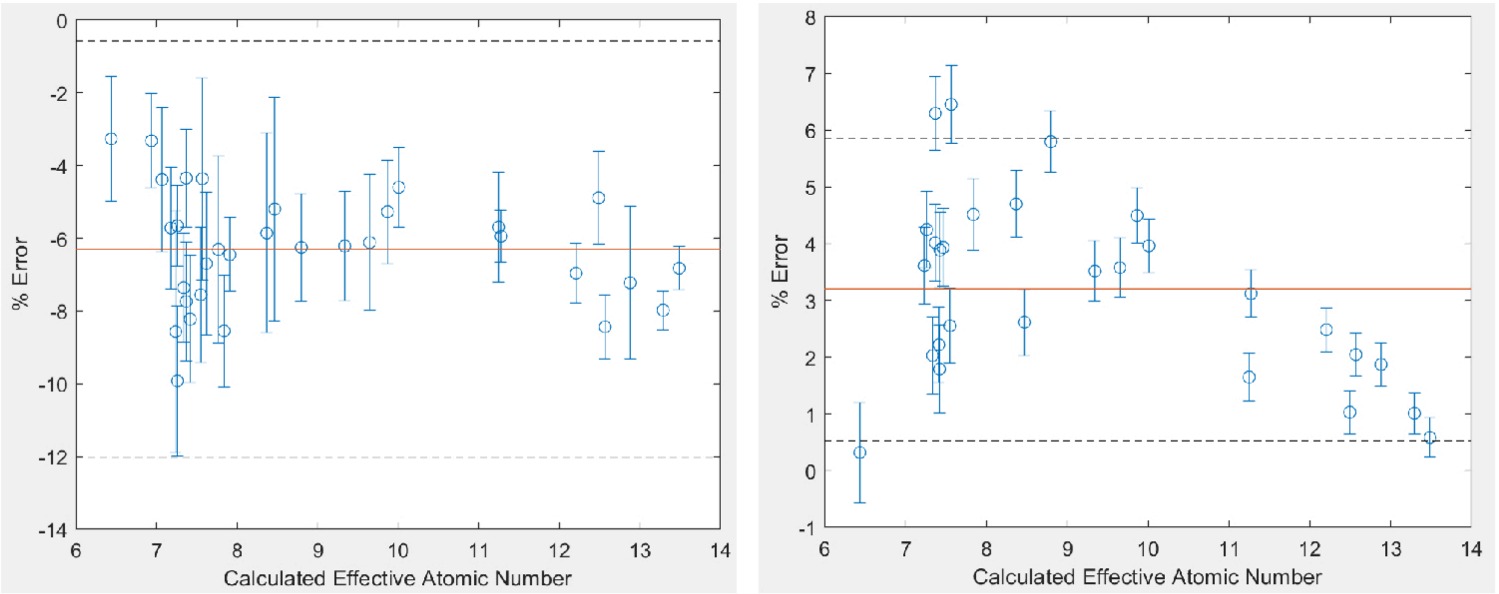
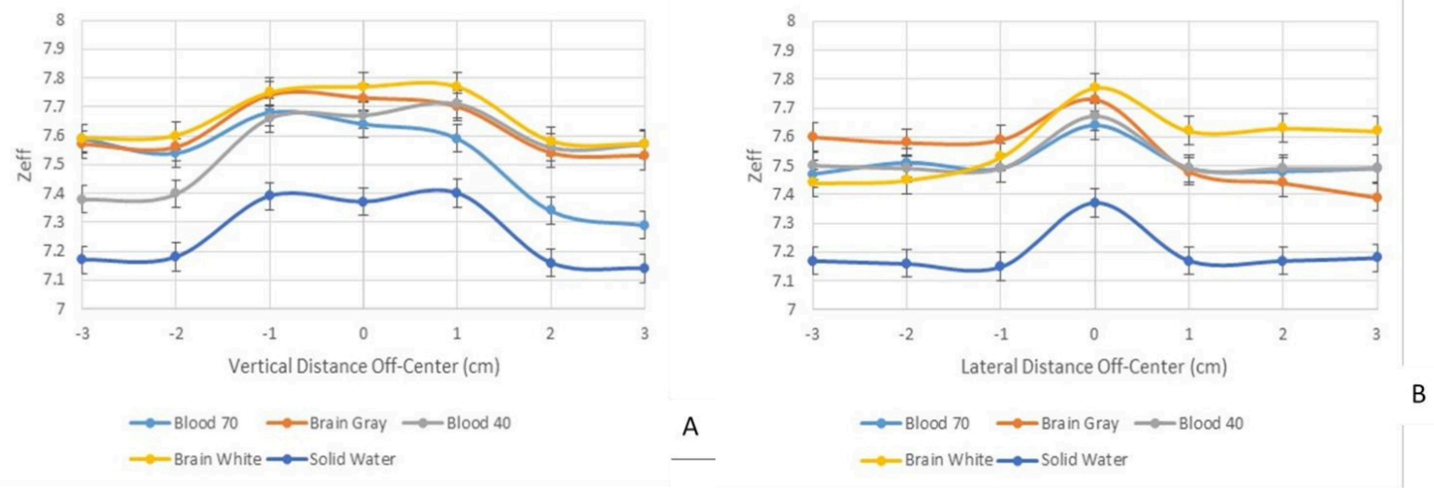


Fig 1. Bland-Altman plot of the percent error against the calculated Z_{eff} values in the (Left) body phantom and (Right) head phantom



. Fig 2. Measured Zeff as a function of the offset distance of the phantom from center in the A) vertical (anterior/posterior) direction and B) lateral direction

CONCLUSIONS

- Z_{eff} and ρ_e can be accurately measured using a DECT acquisition on a Canon Aquilion One Genesis scanner
- Effective Z and Electron Density software performed better when measuring the head phantom
- The system has shown a dependence on phantom positioning within the gantry as well as a positional dependence within the phantom itself
- Presence of a bias may require calibration for accurate measurements
- Bias in Z_{eff} and ρ_e measurements can make it difficult for the application of this information, especially the application of absolute Z_{eff} and ρ_e measurement values. We suggest to instead use relative values (relative to healthy tissue) as indicators of pathology

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DISCLOSURES

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