An Evaluation of Metal Artifact Reduction Reconstructions Using Virtual Monoenergetic Images Acquired with Dual-Energy CT

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Introduction

◦ Instead of a classical monoenergetic beam, as with Single Energy Computed Tomography (SECT), Dual Energy Computed Tomography (DECT) switches rapidly between high and low kVp to recreate two monoenergetic scans[1]

◦ In this case, switching between 80kVp and 140kVp in 0.25ms to generate two sets of spectral data, which are then combined to produce a full spectral dataset, and generate Virtual Monoenergetic Images (VMIs) and Metal Artifact Reduction (MAR) images, amongst others[1]

◦ DECT has the potential to generate images with different and better contrast, and improve target detection and contour quality, while remaining dose neutral[1]

◦ MAR reconstructions are useful for patients with metal implants, including dental and orthopedic implants, which can otherwise severely degrade image quality[1,2]

◦ Some of the main contributors to metal artifacts are beam hardening, photon starvation, scattering, and edge effects – all of which can be helped by DECT, through oscillating high and low energy inputs[2]

◦ With DECT, MAR reconstructions use inputs from both high and low energy scans which results in better low contrast resolution, spatial resolution, and image integrity – the figures below, at matching window/level settings, highlight the difference in input[1,2]

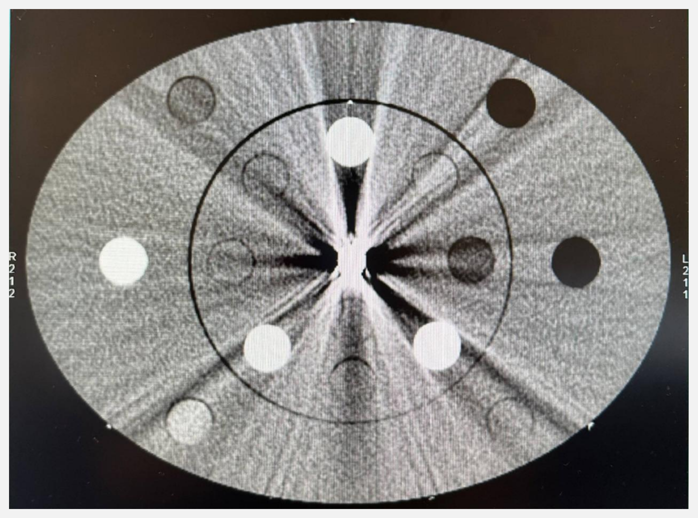

Fig. 1: DECT Scan Reconstructed at 70keV

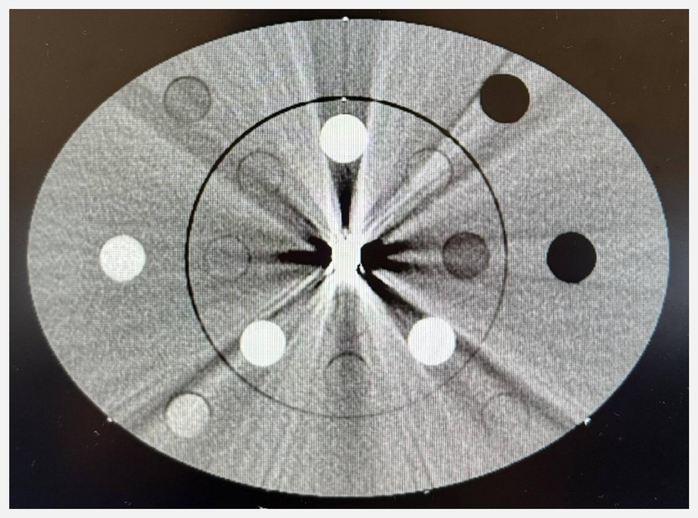

Fig. 2: DECT Scan Reconstructed at 140keV

Purpose

While the use of MAR software for Head and Neck CT scans has been thoroughly documented, there is a lack in the currently available literature regarding the use of MAR in DECT. Gemstone Spectral Imaging (GSI), a DECT implementation, can be used to create VMIs with MAR. Reliable scanning is a fundamental step in radiation treatment planning, and as such this study aims to be one of the first to quantify the effectiveness of GSI MAR reconstructions using VMIs with a focus on Head and Neck patients, and the subsequent impact to image quality, relative electron density, and dose.

Methods and Material

- Using the GE Revolution Apex™ CT Scanner, three separate scanning protocols were applied to investigate image quality of MAR reconstructed 120kVp-like VMIs
- Clinical Head and Neck protocols were used to establish noise and dose matching, using GE's automated DLP values, and the associated scanning parameters
- The protocols were as follows:
  - SECT at 335mA and 120kVp
  - DECT at 445mA and 120kVp-like DM
  - DECT at 405mA and 120kVp-like NM
- For each protocol, the Sun Nuclear Advanced Electron Density phantom was used to quantify the change in Hounsfield Units (HU) in metal using Aluminium (Al), Titanium (Ti), and Stainless Steel (SS) inserts, and a custom-made Tungsten Carbide (WC) insert, as well as the correlated Electron Density Curves (EDCs) for each metal
- Furthermore, image quality was assessed using Sun Nuclear's IQPhan™ and the associated RapidCHECK™ software, as well as visually to assess geometric distortion in the MAR reconstructions for each metal insert
- Visually, the geometric distortion was assessed using an ROI to find the cross-sectional area, with a measurement taken every 10 slices, and then averaged
- To analyze each EDC, the measured HU and their respective best-fit lines were used to calculate each relative electron density (RED) value
- The calculated RED values from the DECT DM and DECT NM scans were then compared to the calculated RED values from the SECT scans, to find the percent difference and absolute difference

Results

- Across all three scanning protocols, the measured HU values – for a range of inserts, not including the metals themselves – of the MAR reconstructed scans remained stable, as seen in figures 3 through 6 below
- Among figures 3-6 , the maximum change in RED was 1.46% and was the difference between the SECT and DECT NM scans for Tungsten Carbide – the highest density metal – with respect to the insert 455 Lung LN-300 - the lowest density insert

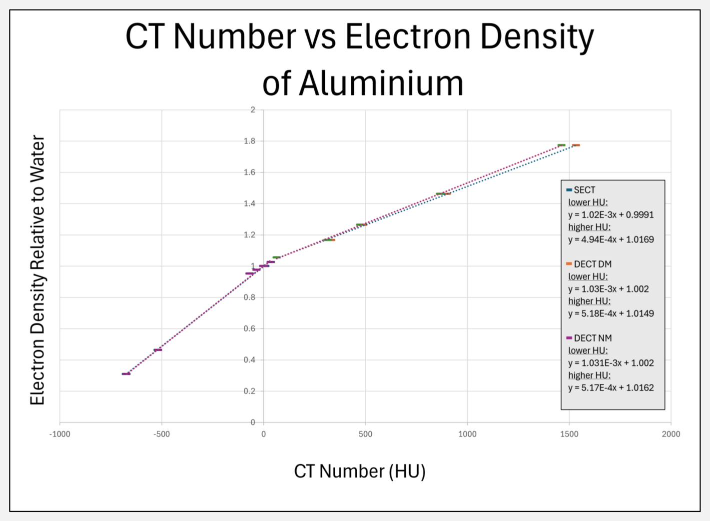

Fig. 3: EDCs for MAR Al Scans

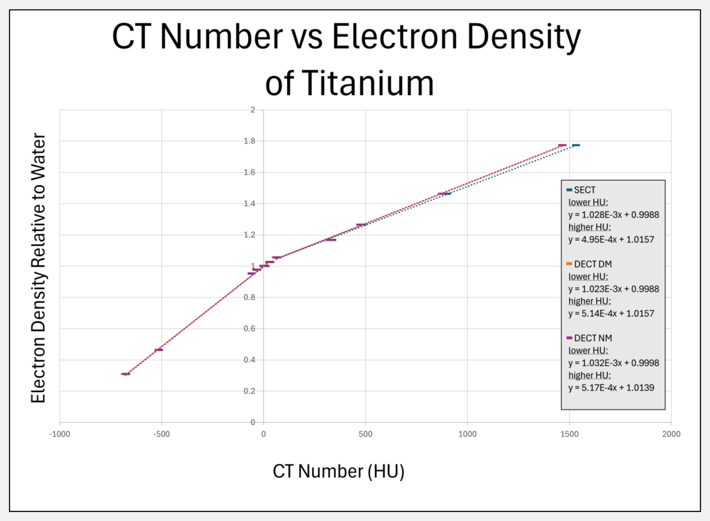

Fig. 4: EDCs for MAR Ti Scans

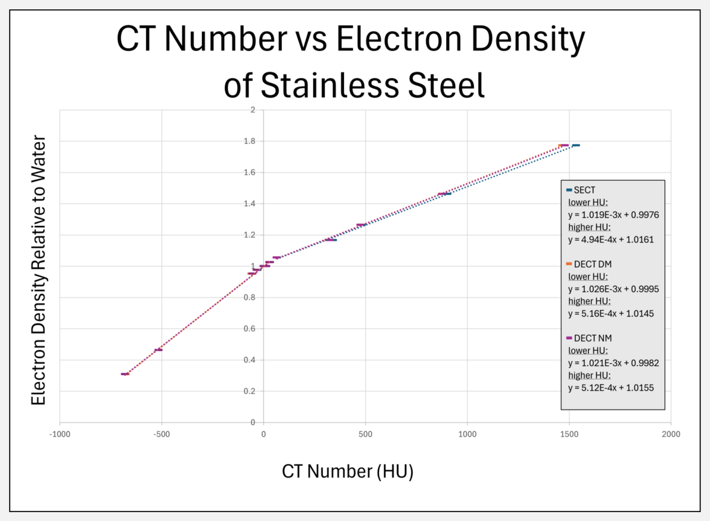

Fig. 5: EDCs for MAR SS Scans

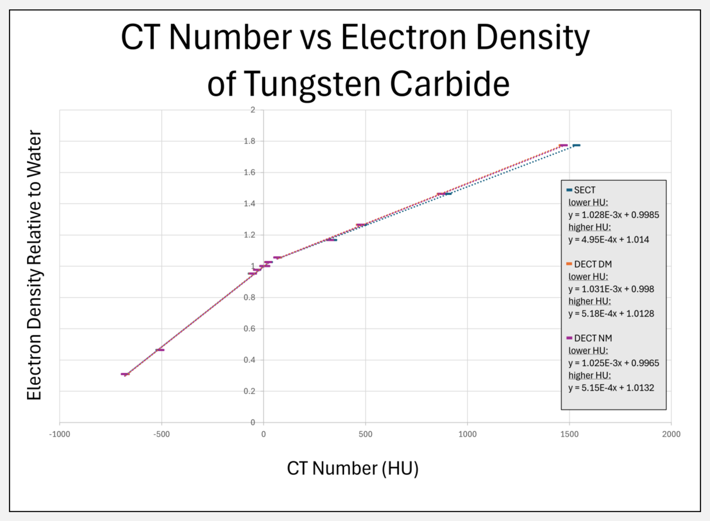

Fig. 6: EDCs for MAR WC Scans

Table 1: Max ΔRED for Each MAR Reconstructed Metal

Metal	Max ΔRED	Scan Type	Insert
Al	0.85%	DECT DM	Solid Water
Ti	1.27%	DECT DM	455 Lung LN-300
SS	0.67%	DECT NM	True Water
WC	1.46%	DECT NM	455 Lung LN-300

- Moreover, the average ΔRED for each metal and scanning type remained less than or equal to 0.60%, as seen in Tables 2 & 3
- The EDC below – fig. 7 - highlights the relationship between material density and absolute difference in RED

Table 2: Avg. ΔRED for Lower HU Best-Fit Lines

Metal	Scan Type	Avg ΔRED
Al	DECT DM	0.23%
Al	DECT NM	0.19%
Ti	DECT DM	0.53%
Ti	DECT NM	0.29%
SS	DECT DM	0.13%
SS	DECT NM	0.32%
WC	DECT DM	0.36%
WC	DECT NM	0.60%

Table 3: Avg. ΔRED for Higher HU Best-Fit Lines

Metal	Scan Type	Avg ΔRED
Al	DECT DM	0.29%
Al	DECT NM	0.19%
Ti	DECT DM	0.15%
Ti	DECT NM	0.14%
SS	DECT DM	0.11%
SS	DECT NM	0.16%
WC	DECT DM	0.25%
WC	DECT NM	0.23%

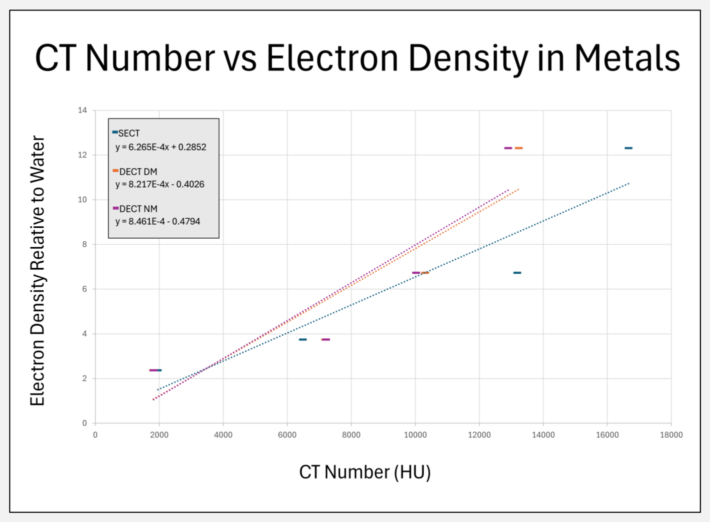

Fig. 7: EDCs for Al, Ti, SS, & WC

- The absolute difference in RED: Al 0.424 DECT DM & 0.447 DECT NM; Ti 1.152 DECT DM & 1.274 DECT NM; SS 0.475 DECT DM & 0.539 DECT NM; WC 0.251 DECT DM & 0.287 DECT NM
- The largest percent difference in RED was 34.8% Al DECT NM
- Due to the small numbers and comparatively large change, to accurately compare ΔRED this study will consider absolute difference for metals, as opposed to percent difference

Table 4: Summary of Image Quality and Dose

Scan Type	DLP [mGy*cm]	MTF 10% [lp/mm]	Uniformity	Low Contrast Detection 0.3%[mm]	Low Contrast Detection 0.6%[mm]	Low Contrast Detection 1.0%[mm]	Low Contrast Detection 2.0%[mm]
SECT	672.6	5.72	0.97	22.8	11.3	6.7	3.2
SECT MAR	""	5.72	0.97	22.8	11.3	6.7	3.2
DECT DM	663.3	5.54	1.53	NA	13.6	8.0	3.8
DECT DM MAR	""	5.54	1.53	NA	13.6	8.0	3.8
DECT NM	598.5	5.59	1.41	NA	13.5	8.0	3.8
DECT NM MAR	""	5.59	1.41	NA	13.5	8.0	3.8

Fig. 8: Metal Insert Reconstructed w/ a 'Smoother' Edge

Fig. 9: Metal Insert Reconstructed w/ a More Defined Edge

- Visually, the measured difference in geometric distortion varied due to some inserts reconstructing with a 'smoother', but larger and less accurate border, as seen in figures 8 & 9

Table 5: Summary of Visual Geometric Distortion w.r.t Cross-Sectional Area

Metal	SECT [mm^2]	DECT DM [mm^2]	DECT NM [mm^2]	Actual [mm^2]
Al	159.20	171.70	168.34	126.67
Ti	142.66	169.94	181.12	126.67
SS	157.28	187.80	202.50	126.67
WC	248.12	258.78	250.72	201.06

Discussion

- These findings demonstrate that DECT 120kVp-like scans produce VMIs that are comparable in image quality, electron density, and patient dose to 120kVp SECT scans
- The change in relative electron density between SECT scans, and DECT DM and DECT NM, respectively, did not exceed 1.5% for any insert, not including metal
- The largest absolute difference in relative electron density between SECT and DECT scans with respect to the metals was 1.274 Ti DECT NM
- The variation in cross-sectional area can partly be attributed to ambiguous border delineation
- Further investigations will look to establish dose and noise matching DECT protocols to clinical Pelvis protocols, as well as combining other GSI images types
- Although this center has not yet implemented DECT technology clinically, quantifying the effectiveness of GSI scans, including MAR scans, is a fundamental first step in ensuring reliable scanning

References

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2. Selles, M., van Osch, J. A. C., Maas, M., Boomsma, M. F., & Wellenberg, R. H. H. (2024). Advances in metal artifact reduction in CT Images: A review of traditional and novel Metal artifact reduction techniques. European Journal of Radiology, 170, 111276. https://doi.org/10.1016/j.ejrad.2023.111276

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