2026 JULY 19–22 VANCOUVER, BC
JOINT AAPM | COMP MEETING

Use of Dual Source Dual Energy CT for Photon-Based Dose Calculation In Radiation Oncology – a Comparative Study Based on Virtual Monoenergetic and Conventional 120 kVp Images

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INTRODUCTION

Dual-energy CT (DECT) is a tool used to differentiate high atomic number materials by using two different x-ray spectra, a low energy and high energy. Tissue characterization can be acquired based on these two absorption measurements because of the energy, atomic number, and density dependent properties of x-ray attenuation. The benefit of DECT in diagnostic applications has been widely studied and proven. Using its ability to reconstruct synthetic images such as Virtual Monoenergetic Images (VMIs), material-specific or material-removed images, and quantitative images of electron density and effective atomic number have helped with the diagnosis of multiple ailments.

Building on its established role in diagnostic imaging, DECT is increasingly being investigated for a variety of applications in radiation oncology.

The objective of this study was to evaluate the feasibility of using DECT VMIs in radiation therapy planning, using two different dose calculation algorithms, Anisotropic Analytical Algorithm (AAA) and Acuros XB (AXB). This objective was achieved by looking at three specific aims:

1. To assess the impact of VMIs on dose calculations in the Eclipse TPS for two different tissue-equivalent targets and two different therapy beam energies.
2. To evaluate changes in contoured volume across different VMIs.
3. To evaluate the image quality of VMIs compared to the standard 120 kVp image.

Each phantom was scanned using the following protocols on a Siemens SOMATOM dual-source dual-energy CT:

	Single Energy	Dual Energy
Tube Potential	120 kVp	80 kVp & 140 kVp Sn
Tube Current	110 mAs	247 mAs & 95 mAs
Collimation	128x0.6 mm	40x0.6 mm
Pitch	0.6	0.6
Rotation Time	0.5 s	0.5 s
Reconstructed slice thickness	5 mm	5 mm
ADMIRE	off	off
iMar	On for pacemaker	On for pacemaker

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METHODS AND MATERIALS

HU-to-density curve generation:
- Scanned a CIRS Electron Density phantom to acquire HU values for known tissue-equivalent materials
- Generated curves for 40, 60, 80, and 190 keV in Eclipse for subsequent use in the treatment planning process

Catphan 500 Phantom:
- was scanned, and the sensitometry module slices were used to create treatment plans for two of the targets.

Creating treatment plans:
- The HU curves generated in this study were paired with their corresponding Catphan datasets for treatment plan creation.
- Two Lateral photon beams were used, each delivering 100 MU
  - Performed this for both 6X and 15X
- Chose two targets on the Catphan images:
  - LDPE for a low-density material
  - Teflon for a high-density material

Volume comparison:
- The volume of 4 targets in the CIRS phantom were measured in Eclipse and compared to their actual volume.

Image Quality:
- Another set of images from the Catphan phantom were done.
- With these images the following tests were done: noise, uniformity, contrast-to-noise ratio, MTF, and the Noise power spectrum.

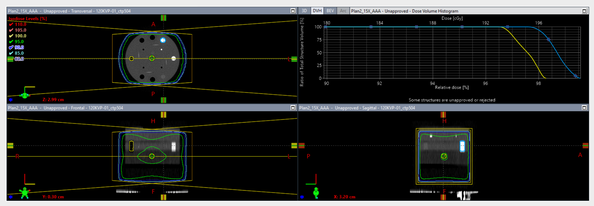
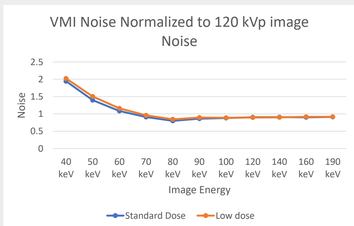


Figure 1. Treatment plan for the Catphan 500 Phantom at an image energy of 120 kVp and beam energy of 15X for AAA. Yellow is the LDPE insert and Blue is the Teflon insert

RESULTS

	Adipose Target Volume (cm^3)	Cortical Bone Target Volume (cm^3)	Liver Target Volume (cm^3)	Lung Target Volume (cm^3)
120 kVp	83.63	101.42	77.34	102.58
40 keV	83.73	101.42	77.85	103.02
60 keV	83.73	101.50	77.85	103.02
80 keV	83.73	101.50	77.86	103.02
190 keV	83.73	101.50	77.85	103.02

Table 1. Delineated target volumes for the Adipose, Cortical Bone, Liver, and Lung used the CIRS Electron Density phantom. Actual volume being between 91-105 cm^3



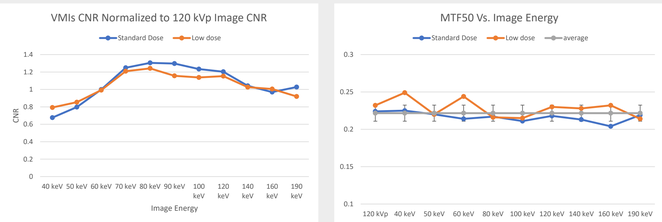


Figure 2. Diagnostic tests for VMIs from 40-190 keV compared to 120 kVp. The noise and CNR VMI values are normalized to 120 kVp.

RESULTS

- The dose calculation results can be traced back to the image quality and how it effects the stability of the HU values
  - Images with more noise result in unstable HU values
  - Better overall image quality results in more stable HU values
- VMIs between 60-80 keV show equivalent or improved image quality and dose calculation to 120 kVp
  - They have reduced noise, maximized CNR, and the most stable HU values.

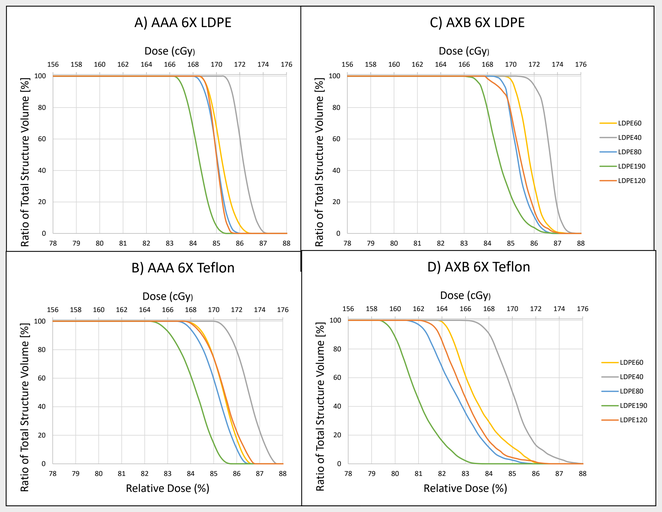


Figure 3. 6X DVH curves. (A) AAA 6X DVH for the LDPE insert. **(B)** AAA 6X DVH for Teflon insert **(C)** AXB 6X DVH for LDPE insert **(D)** AXB 6X DVH for Teflon insert

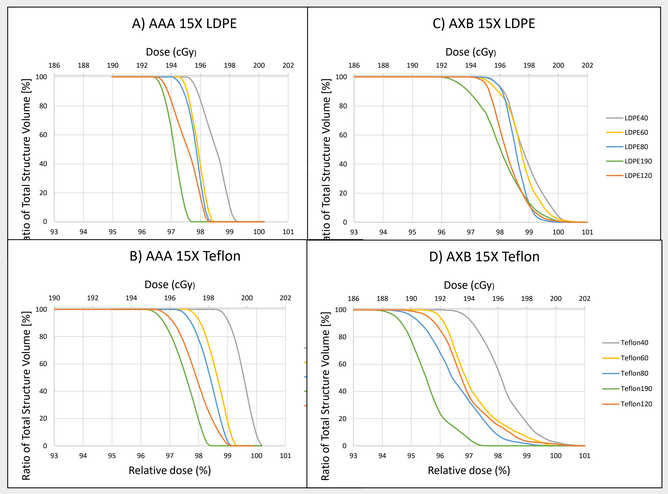


Figure 4. 15X DVH curves. (A) AAA 15X DVH for the LDPE insert. **(B)** AAA 15X DVH for Teflon insert **(C)** AXB 15X DVH for LDPE insert **(D)** AXB 15X DVH for Teflon insert

	Average Relative Dose Percent Difference for LDPE			
	40 keV	60 keV	80 keV	190 keV
6X				
AAA	1.343	0.292	0.118	0.947
AXB	1.398	0.527	0.195	0.847
15X				
AAA	0.994	0.423	0.285	0.403
AXB	0.541	0.406	0.356	0.378

	Average Relative Dose Percent Difference for Teflon			
	40 keV	60 keV	80 keV	190 keV
6X				
AAA	1.263	0.116	0.372	1.527
AXB	2.301	0.684	0.520	2.465
15X				
AAA	0.817	0.143	0.360	1.235
AXB	1.202	0.413	0.514	1.511

Table 2. Average percent differences between each VMI plan and 120 kVp reference plan

DISCUSSION

- The 60 and 80 keV VMIs provide dose calculations closely matched to 120 kVp.
  - Having a percent deviation <1% for both targets and treatment beam energies.
- Energies outside the 60-80 keV range show larger deviations, reaching > 2% in the case for the Teflon target at 6X using AXB.
  - However, these images provide improved image quality compared to the 120 kVp with either improved image contrast or artifact reduction (metal and beam hardening).
- These monoenergetic image trends are expected to be clinically representative, as HU curves for tissue-equivalent materials follow similar patterns across the range of human tissue densities.
  - Further studies would be required to assess whether the observed trends persist for materials with densities higher than Teflon, such as metals.
- AXB demonstrated greater sensitivity to HU variations in high density Teflon than AAA, particularly for the 6X beam energy, while algorithm-dependent variations for LDPE remained consistent across image energies
  - The greater HU variability of Teflon over the 40-190 keV range, relative to LDPE, results in larger AXB-AAA dose calculation differences for Teflon.
  - AXB exhibits greater sensitivity to tissue heterogeneities than AAA, making it more susceptible to variation in HU.
- These algorithm- and material-dependent effects are more pronounced for the lower energy 6X treatment beam.
- There was no energy dependence shown on the contoured volume.
  - Further investigation is needed, especially with something with a nonuniform volume

CONCLUSIONS

- DECT-derived VMIs could potentially be integrated into the radiation therapy workflow.
  - Further investigation with clinical patient data and rigorous HU validation is necessary.
- 60-80 keV show to be the most suitable for radiation therapy planning.
  - While this is the ideal energy range compared to the 120 kVp, other energies could be considered and might be found more appropriate with more research and advanced dose calculation algorithms.
- If VMIs were to be used, a threshold needs to be determined on how much of a variation in dose from the 120 kVp standard is acceptable.
- VMI effects on dose calculations are dependent on treatment beam energy, materials, and dose. calculation algorithm

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