Evaluation of a New Multi-Energy QA Phantom for Spectral CT:

Optimization of Diagnostic Image Quality with Virtual Monochromatic Imaging (VMI)

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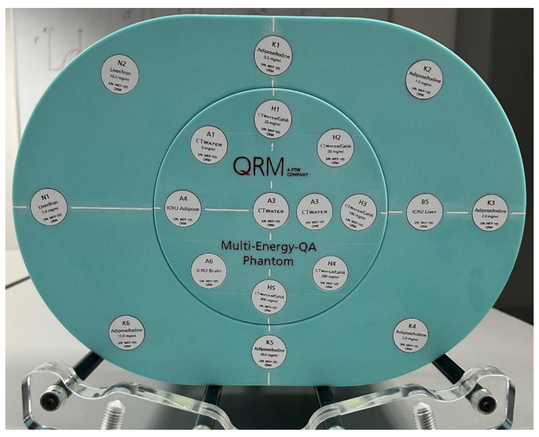
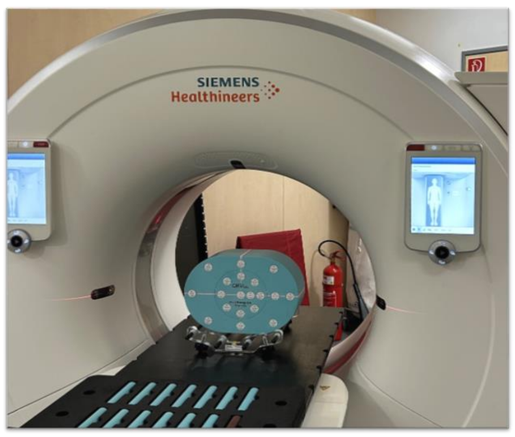
Motivation

Spectral computed tomography (CT) enables more precise and quantitative medical imaging. Virtual monoenergetic reconstructions and iodine quantification can contribute to optimizing diagnostic image quality, as tissue differences can be visualized much more clearly [1,2]. To evaluate this potential, we examined a newly developed multi-energy quality assurance (QA) phantom (QRM, PTW, Germany) containing multiple inserts of different materials and concentrations, assessing the accuracy of iodine and calcium hydroxyapatite (CaHA) quantification in spectral CT imaging.

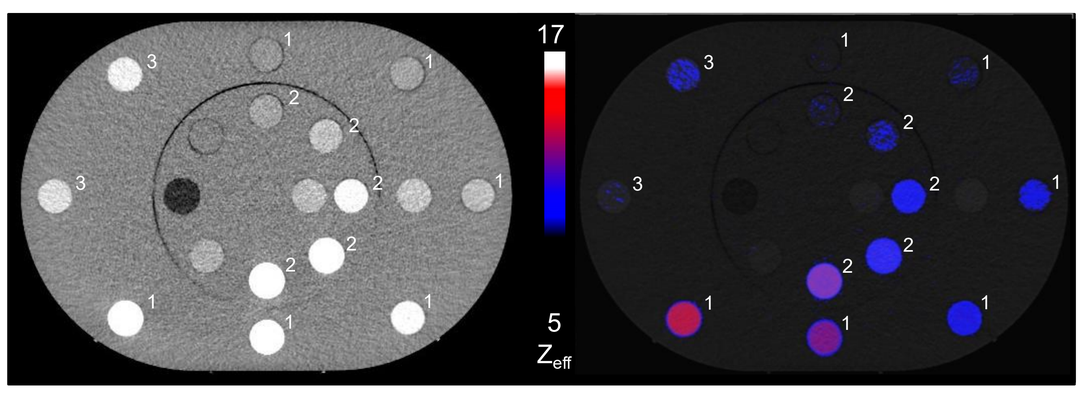
Multi-Energy QA-Phantom

A multi-energy QA phantom composed of tissue-equivalent materials and calcium hydroxyapatite (CaHA) inserts for bone simulation, along with clinically relevant contrast agents, such as iodine and iron at varying concentrations, was scanned using dual-energy CT (DECT, Siemens Somatom Confidence).





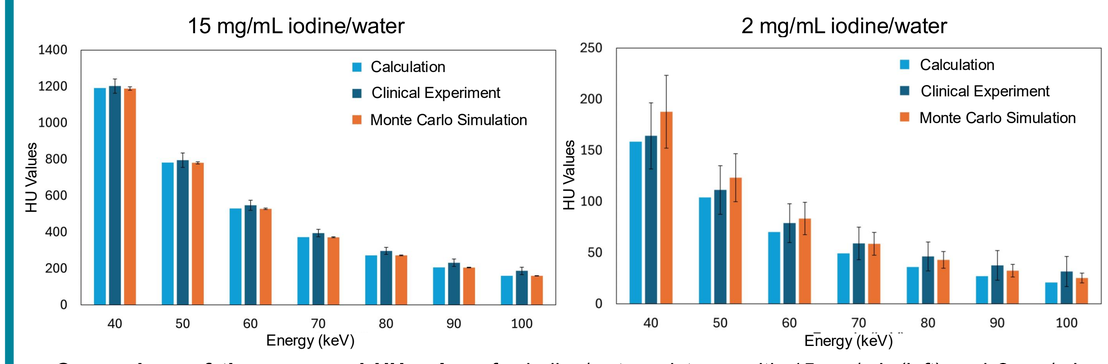
Virtual monoenergetic images (VMI) ranging from 40 keV to 190 keV were reconstructed and analyzed to evaluate image quality and the optimization of iodine contrast at different energy levels. In addition, maps of the effective atomic number (Z_{eff}) were generated to verify the accuracy of the system. The results showed very good agreement with the manufacturer's specifications.



80 keV **virtual monoenergetic image** (VMI) (left). **Map of the effective atomic number** (Z_{eff}, right). The color scale represents the corresponding Z_{eff} values of the materials. The phantom contains inserts with different contrast agents: 1 – water/iodine, 2 – water/CaHA, 3 – liver/iron.

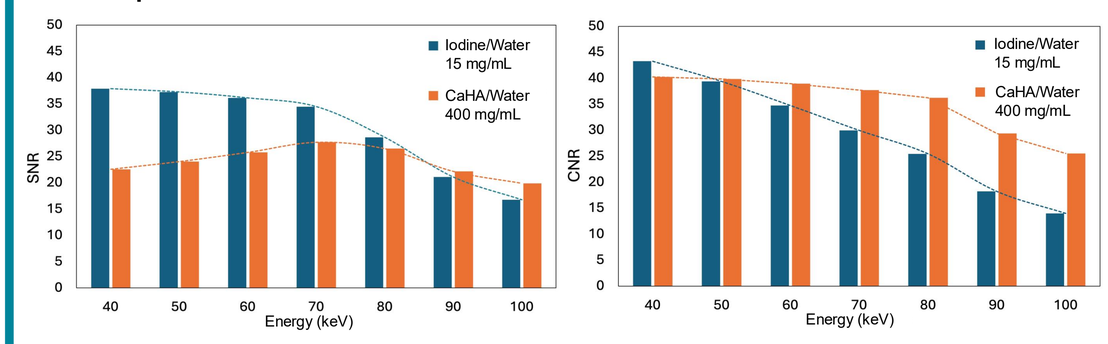
Optimization of Image Quality Using VMIs

The Hounsfield units (HU) determined for the virtual monoenergetic images (VMIs) were compared with Monte Carlo simulations as well as with theoretically calculated reference values. For the iodine/water mixtures at different concentrations, a close agreement was observed between the measured, simulated, and theoretical HU values across the entire energy spectrum.



Comparison of the measured HU values for iodine/water mixtures with 15 mg/mL (left) and 2 mg/mL (right) against theoretical calculations and Monte Carlo simulations across the VMI energy range. A close agreement is observed between all data sets.

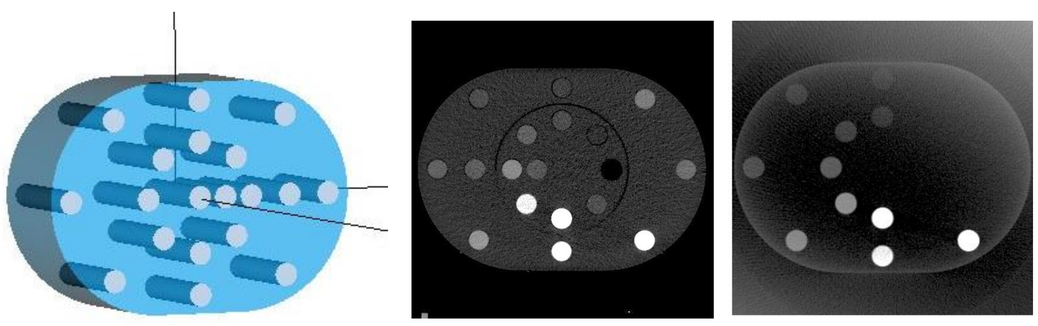
To evaluate image quality, iodine and CaHA inserts were analyzed. Iodine showed higher SNR and CNR values at lower energies, while CaHA remained relatively stable. However, very low energies increased image noise. Therefore, an optimal balance was found in the range of 70–90 keV, where iodine and CaHA can be clearly distinguished and the noise level remains clinically acceptable.



Profiles of **signal-to-noise ratio (SNR)** and **contasrt-to-noise ratio (CNR)** for a 15 mg/mL iodine insert and a 400 mg/mL CaHA insert across the diagnostically relevant VMI energy range, based on the measured data.

Monte Carlo Simulation

The QRM phantom was also simulated using Monte Carlo methods and the resulting VMIs closely matched the characteristics of the real CT acquisitions.



Virtual monoenergetic images (VMI): QRM phantom model (left), 70 keV VMI from a CT scan of the real phantom (center) and the corresponding 70 keV VMI from the Monte Carlo simulation (right).

References

[1] Vrbaski et al., "Quantitative performance of photon-counting CT at low dose: Virtual monochromatic imaging and iodine quantification," *Medical physics*, 2023

[2] Cester et al., "Virtual monoenergetic images from dual-energy CT: systematic assessment of task-based image quality performance," *Quantitative imaging in medicine and surgery*, 2022

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