LESION DETECTABILITY ON DUAL ENERGY COMPUTED TOMOGRAPHY ABDOMINAL IMAGING: PHANTOM STUDY

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Abstract—**Background:** Computed Tomography (CT) is a widely used imaging modality to detect and diagnose liver tumors. The early detection of hepatic lesions is crucial because the treatment for liver malignancy is most effective when the tumor is small (≤ 2 cm). The major problems of small hepatic lesion detection in CT are lower lesion-to-liver contrast in nature and higher noise level relative to other organs. Many studies [1] suggested the detectability of low contrast liver lesion in CT depends on acquisition and reconstruction parameters, lesion characteristics, radiation dose and patient diameter.

Dual-energy computed tomography (DECT) is considered a promising new development in CT that had a potential to improve lesion detection and characterization beyond the levels currently achieved by conventional single energy CT. Based on reconstructed low- and high energy images can create virtual monochromatic images at energy E as a weighted average of the CT number at low (CT^L)- and high-energy (CT^H) scans, which is given by

$$CT(E) = w(E) \cdot CT^L + [1 - w(E)].CT^H \quad (1)$$

where L and H represent low- and high-energy, respectively and w represents weighting factor is given by

$$w(E) = \frac{\mu_1(E)\cdot\mu_2^H - \mu_2(E)\cdot\mu_1^H}{\mu_1^L\cdot\mu_2^H - \mu_1^H\cdot\mu_2^L} \cdot \frac{\mu_2^L}{\mu_2(E)} \quad (2)$$

where "μ" is linear attenuation coefficient, 1 and 2 represent the two basis materials.

Therefore, the monochromatic image generated from image space data is simply a linear combination of the two CT images at low and high energies, where the sum of the two weighting factors equals 1.

The purpose of generating the monochromatic images in the image domain is primarily to generate a single optimized set of images for routine diagnosis.

The aim of this study is to investigate the lesion detectability in low keV-VMC (virtual monochromatic) images from dual energy and low kVp images from single-energy CT and to determine the characteristic of lesion detection in different phantom size and kV combinations in dual-energy CT.

Methods: A semi-anthropomorphic abdomen phantom (QRM Moehrendorf, Germany) with two additional rings represent the abdominal size of small, medium and large adults (Fig.1). The phantoms were acquired in both dual- and single-energy scans with a dual-source CT scanner (Somatom® Force, Siemens Healthineer, Germany). The single energy (SE) scans were acquired at kVp 80, 100, 120, each scan using the same radiation output, expressed by $CTDI_{vol}$ (a standard 32cm-CTDI phantom), as in a typical clinical protocol performed at 120 kVp. The $CTDI_{vol}$ were 7.3, 10.5, 14.5 mGy for small, medium and large phantoms, respectively. For each phantom size, three dual energy (DE) acquisitions were performed at the same $CTDI_{vol}$ as in the SE scans using the different kVp combinations of 80/150Sn, 90/150Sn and 100/150Sn.

The VMC images at 4 energy levels (40, 50, 60, 70 keV) were then created using Syngo Dual Energy Application, Siemens, Healthineer (Fig. 1.) for each phantom size and each scan setting. Only low keV (40-70) images were investigated in this study because these energy levels provide a superior contrast than the higher energies and is comparable to the low kVp SE images.

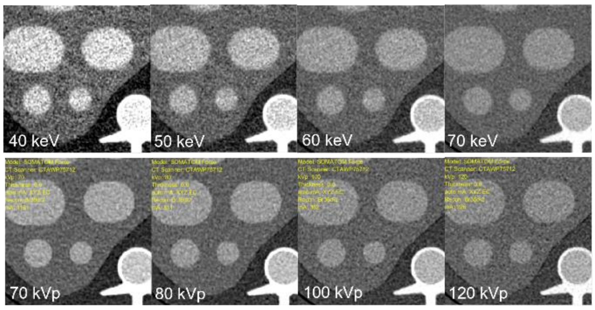

Fig. 1. The abdomen phantom images; the top row is generated VMC images of at 40, 50, 60 and 70 keV from a dual-energy scan with 80/150Sn kV combination and the bottom row is conventional axial images reconstructed from SE scan at 70, 80,100 and 120 kVp.

The lesion detectability of virtual monochromatic images from DECT scan) and polychromatic images from SECT scan, were analyzed by using conventional matrix; in term of contrast to noise ratio (CNR) and task-based images quality matrix; in term of detectability index, *d'*.

For each single and dual energy data sets, the CNRs were calculated by measuring the CT number of hyperdense liver lesion and adjacent uniform liver background, and noise in the liver background.

To calculate a detectability index, *d'*, the imQUEST software version 6.01 designed by Duke CIPG had been used. A method of non-pre-whitening observer model with eye filter (NPWE) that incorporated the resolution, noise texture, diagnostic task, and viewing conditions[2], were selected in this study, *d'* was obtained from equation (3),

$$d'^2 = \frac{[\iint W(r)^2.TTF(r)^2.V(r)^2 r dr]^2}{\iint W(r)^2.TTF(r)^2.V^4.NPS(r) r dr + \iint n_i.W(r)^2.TTF(r)^2.NPS(r) r dr} \quad (3)$$

where *W* is a task function, *r* is radial spatial frequency, *TTF* is task transfer function, *V* is visual response function, *dr* is radial variable, *NPS* is noise power spectrum, and n_i is internal noise of the eye.The lesion sizes were 5, 10 and 20 mm diameter in *d'* calculation

Results: CNR as a function of virtual monochromatic energy (40, 50, 60 and 70 keV) for each phantom size is plotted for different kV combinations in dual-energy scans (Fig. 3). The maximum CNR for each phantom size was found at 40 keV and the CNR gradually decreases when increases the monochromatic energy. At these VMC energies, CNRs at all phantom size were higher than that of a conventional SE scan at 120 kVp except at 70 keV from 80/150Sn. The use of low kV SE-scan at 70, 80 kVp showed superior result in CNR compare to VMC images.

The impact of kV combination was also observed in this study, as increasing the difference between of low and high tube voltage (from 80 kV to 100 kV combined with 150Sn), CNR is improved for all phantom sizes except at large phantom size, the use of 90/150Sn kV combination has a higher CNR compare to other kV combinations.

For small lesion sizes of 5 mm, using DECT showed inferior result in *d'* compare to 120 kV SE scans. However, at larger lesion size of 10 and 20 mm, the VMC images provide improved d' compare to 120 kVp SE scan. The SE-scans at 70 and 80 kVp provide better *d'* compared to low energy VMC images in all lesion sizes for each size of phantom.

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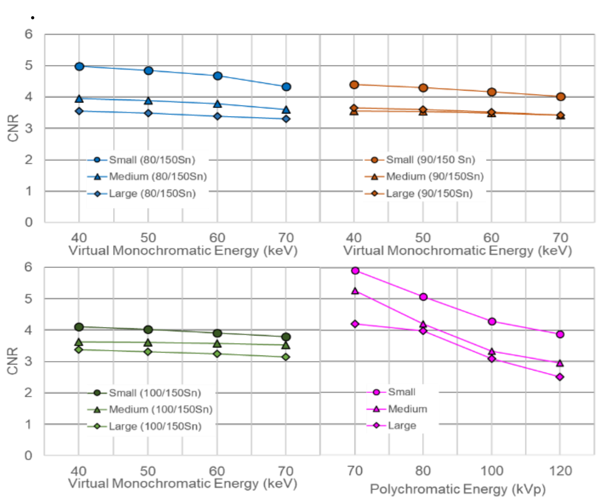

Fig. 2 CNR as a function of monochromatic energy for the three phantom sizes and three kV combinations of 80/150Sn, 90/150Sn and 100/150Sn in dual-energy scan, as well as the CNR as a function of polychromatic energy of single-energy scans for the three sizes of phantom.

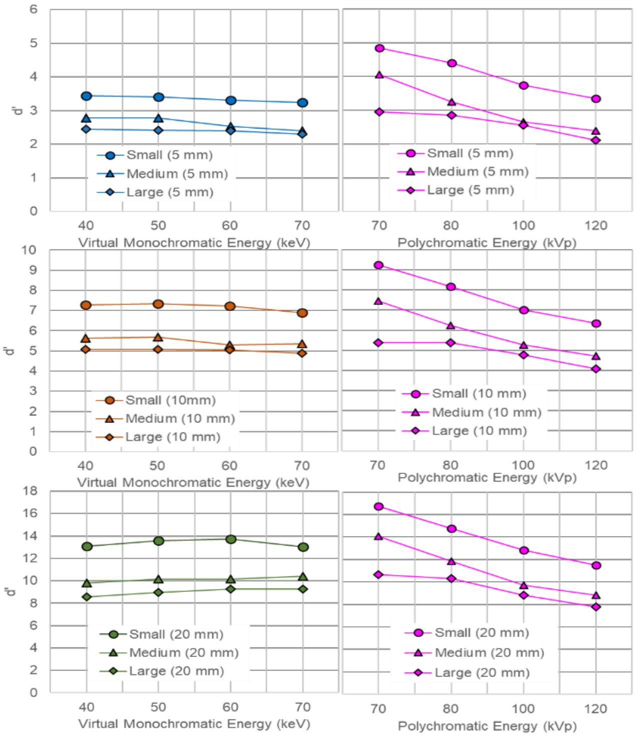

Fig. 3 Detectability index *(d)'* for 5-,10- and 20-mm lesion sizes as a function of monochromatic energy for the three phantom sizes at 80/150Sn in dual-energy scan were plotted, as well as *d'* in different polychromatic energy of single-energy scans.

Conclusion: The lesion detectability were evaluated among the use of low energy VMC images in DECT and low kV in SECT-scans. The larger different of kV between low and high energy in DECT improves CNR and *d'* especially in small phantom size. For a small lesion size (5mm) using low kVp SE-scan showed superior outcome on *d'* than the DECT scan.

References:

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Keywords— dual-energy CT, virtual monochromatic image, detectability index, lesion detectability, abdomen dual-energy CT

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