Optimisation of DECT Spectral Separation for Quantitative Evaluation of Clinical Contrast Agent

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Abstract: This study is focusing on the evaluation and optimization of the spectral separation of clinical contrast agents in DECT imaging. Based on previous literatures, the two most important methods to evaluate the DECT systems are the evaluation of the DE ratio and the contrast to noise ratio. In the first study, abdomen CT phantom was used with an insertion of three contrast media: iodine, gadolinium and milk. The phantom was scanned using abdomen routine protocols for both single and dual energy CT. The scanner was then switched from DECT to SECT to scan the phantom with single energy ranges such as 80 kV, 100 kV, 120 kV and 140 kV. The MATLAB was used to fuse the images by weighted averaging 30 % low energy and 70 % high energy. The collected data were analysed using the Weasis software. Statistical analyses were then performed to compare the contrast to noise ratio with different tube voltage combinations. The MATLAB was again used to fuse the images. The results showed that 80/140 kV is the best spectral separation for evaluation of the clinical contrast medium. In addition, the results displayed significant CNR effect (p < 0.05) for all DECT images. The dual energy technique improved the contrast to noise ratio and dual energy ratio for the DECT images.

1. Introduction
The first CT imaging device was created in 1972 by G. N. Hounsfield [1, 2]. CT is considered as a non-invasive diagnostic tool that allows for 3D visual reconstruction. The first DECT device was introduced in 1987 [3]. Then DECT has been introduced and depends on using two spectra; a dual-energy CT is typically performed using 80 and 140 kV spectra [3-5]. The dual-energy CT was developed to provide the ability of a CT to differentiate between different contrast media. Thus, DECT improves the ability to distinguishes different material [6, 7].The contrast improvement depends on using different X-ray spectra for high and low energy spectra of the evaluated contrast materials [5, 8, 9]. Contrast Medias are radioopaque materials that are not transparent to X-rays. Contrast Medias that have high atomic number (Z) and high density will incline to absorb X-rays better. The X-ray absorption coefficient (µ) relationship is perhaps best expressed in the formula below [2]:

\[ \mu \approx \frac{\rho z^4}{AE^3} \]  

(1)
where \( \rho \) is the density, \( Z \) is atomic number, \( A \) is atomic mass and \( E \) the X-ray energy.

X-Ray computed tomography contrast agents can be administrated orally for G.I.T examination or intravenously for angiography examination. The contrast media that are containing atoms of high atomic number such as gadolinium and iodine are commonly used in diagnostic imaging department to highlight the abnormal lesions better. This study evaluate and optimization the spectral separation of clinical contrast agent in computed tomography imaging.

2. Methods

2.1 Phantom design

Abdomen phantom fabricated from perspex. The phantom have five inserts, which two inserts blocked and filled with water. Remain two inserts filled with known concentrations and volume of iodine and gadolinium and the last insert was filled with milk. The Insert number 1 contained diluted iodine (Atomic number = 53) with concentration 10.34 mg/ml. Insert number 2 contained diluted Gadolinium (Atomic number = 64) with concentration 0.313 M and insert number 3 with Milk. All the contrast agents had the same volume 100 ml.

2.2 Image acquisition

The phantom was positioned on the CT table with the aid of laser light. It was immobilized with form pad to maintain the stability of the phantom in fixed place without movement. The phantom was scanned with SECT technique at different single tube voltage 80, 100, 120 and 140 kV. Also scanned by DECT technique by common tube voltages of 80/140 kV. The CT value difference between the water that surrounds the clinical contrast materials and the water inside the inset was less than 1.5 HU. Measurements for contrast to noise ratio were performed with different X-ray tube voltage combinations for low and high energy.

![Figure 1](image-url)

**Figure 1**: (A) Image of the circular abdomen phantom of diameter 32 cm used to simulate abdomen patients. (B) CT image for the phantom after filled with water to take the background. (C) Tomography image to accurate scan for the phantom.

| Parameters                  | Abdomen protocol DECT |
|-----------------------------|------------------------|
| mAs for 80 [kV]             | 343 [mA]               |
| mAs for 140 [kV]            | 189 [mA]               |
| Pitch factor                | 0.35 and 1.2 [mm]      |
| Slice thickness             | 0.6 and 10 [mm]        |
| Scan mode                   | Spiral                 |
| Exposure Time per Rotation  | 0.5 [s]                |
2.3 Technique for Reconstruction of DECT data

![Figure 2: Technique for reconstruction of DECT images. (A) CT image for the phantom at low energy tube voltage about 80 kV and (B) phantom scanned at 140 kV and (C) the fused image at 80/140 kV.](image)

In our research, The IMMA phantom scanned at several single energy CT were 80, 100, 120 and 140 kV. The images were reconstructed using FBP, and the data were analyzed. The typical fusing technique was performed with weighting factor of 0.3 [10-13]. The 0.3 weighted- average data set are 30% from 80 kV data and 70% from 140 data. As found in this experiment, this weighting factor minimizes the image noise and improved the contrast to noise ratio in VNC images.

2.4 Measurements of contrast noise ratio (CNR) and DE ratio

Using MATLAB program, the attenuation coefficient for X-ray photons was measured for each contrast media in Hounsfield unit (HU) with different pitch value and tube voltage. This measurement was performed by drawing a circular ROI at the areas of interest. The area of the ROI was 60 mm² and was maintained constant for all analysis to decrease bias in measurement [14].

\[ \text{Contrast noise ratio} = \frac{\text{ROI}_m - \text{ROI}_b}{\text{SD}_b} \]  \hspace{1cm} (2)

where; \( \text{ROI}_m \) is the mean attenuation of the contrast media and \( \text{ROI}_b \) is the mean attenuation in background from water. \( \text{SD}_b \) is the image noise, defined by the standard deviation of the pixel values from HU in the ROI. DE ratios of the three contrast agents were measured by dividing the Hounsfield unit (HU) of the low-energy such as 80 kV by mean Hounsfield unit (HU) for high energy such as 140 kV. Where low energy tube voltage is 80, 100 kV and high 120 or 140 kV [5, 15].

3. Results and Discussion

The measured CNR in the combined images at fixed slice thickness is 0.6 mm and minimum pitch value 0.35 and the maximum pitch value 1.2 mm. In addition different X-ray tube voltage combinations as drawn in Figure 4. For all the VNC images the CNR level was higher at 80/140 kV compared with the other tube voltage combination. Gadolinium enhancement in the fused images ranges from 16 to 23 HU for the different pitch value and tube voltage combination. However, the HU for iodine enhancement ranges from 179 to 214 HU. Similarly, the CNR is significantly higher with low pitch compared to high pitch value (P<0.05) (Figure 4). The CNR for all the contrast media, are significantly higher at 80/140 kV (P < 0.05). The highest standard deviation of all contrast agents in the fused images was higher at 80/120 kV.
The measured DE ratios for the different contrast media are presented in matrix color as shown in Figure 5. The values ranged from 1.18 to 3.4, 1.18 to 2.1 and 1.1 to 2.3 for gadolinium, iodine and milk, respectively. The combination voltage of 120/140 kV has the lowest DE ratios, while 80/140 kV has the highest DE ratios (Figure 5).

In this study, the performance of DECT at different X-ray tube voltage combination with constant slice thickness and different pitch values was assessed. Similarly, the CNR for the different contrast agent within the abdomen CT phantom was evaluated (Figure 3). There is apparent and essential difference in CNR between the different tube voltage combinations. The combination voltage of 80/140 kV shows the highest CNR for all the contrast agents, this is as a result of combining images with the highest enhancement that is 80 kV and highest penetration obtained at 140 kV. At low tube voltage (80 kV) the effective energy is similar to the k-edge of iodine and Gd and hence, better enhancement. However, using 80 kV alone will have a limitation of not penetrating the body adequately. The 140 kV will have high energy to penetrate the body but with low contrast. The combination of these two energies will strike a balance between contract and penetration and hence, give a better image with high CNR. This is inline, which study conducted by Graser, A., et al 2009 and they mentioned that 80 and 140 kV tube voltage , lead to optimum maximum material differentiation for materials [16]

Results from Figure 4 shows that 80/140 kV demonstrate the best DE ratio for milk, iodine and Gd, respectively. Gd and iodine are used for IV contrast. However, iodine show superior DE ratio compared to Gd. This is because the attenuation is directly related to the concentration of the contrast media and Gd has a low concentration. Therefore, it is less distinguished with the surrounding background. On the other hand, iodine has high concentration and is more distinguished with the surrounding environment. Milk has shown attenuation difference with the surrounding background. However, it has low attenuation difference compared to iodine. This might be because milk constitute of fat, which makes it have little attenuation.
On the contrary, 120/140 kV tube voltage gives the lowest DE ratio. It accounts for low DE ratio because of the high energy and will lead to more penetration with low attenuation compared to the low energy such as 80 kV. Similarly, the small pitch value shows a high CNR. This might be as a result of the fact that there is more radiation deposited in each slice with low pitch because of the small movement in table per gantry rotation and hence, more CNR.

4. Conclusion
Out of the tube voltage combinations, the highest CNR fused images were obtained using 80/140 kV for Gd, iodine and milk, respectively. This indicate a better image quality. Similarly, low pitch value has improved CNR compared to a high pitch in all the contrast media. Results from the study showed that the DE ratios is higher at 80/140 kV for the different contrast media. This optimizes spectral separation of the various contrast media used.

Reference
[1] Lindsten, J.E., *Physiology Or Medicine: 1981-1990*. 1993: World scientific.
[2] Lusic, H. and M.W. Grinstaff, *X-ray-computed tomography contrast agents*. Chemical reviews, 2012. 113(3): p. 1641-1666.
[3] Krauss, B., et al., *The importance of spectral separation: an assessment of dual-energy spectral separation for quantitative ability and dose efficiency*. Investigative radiology, 2015. 50(2): p. 114-118.
[4] Karcaaltincaba, M. and A. Aktas, *Dual-energy CT revisited with multidetector CT: review of principles and clinical applications*. Diagnostic and Interventional Radiology, 2011. 17(3): p. 181.
[5] Krissak, R., et al., *Gold as a Potential Contrast Agent for Dual-Energy CT*. Advances in Molecular Imaging, 2013. 3(04): p. 37.
[6] Avrin, D.E., A. Macovski, and L. Zatz, *Clinical application of Compton and photo-electric reconstruction in computed tomography: preliminary results*. Investigative radiology, 1977. 13(3): p. 217-222.
[7] Yeh, B.M., et al., *Dual-energy and low-kVp CT in the abdomen*. American Journal of Roentgenology, 2009. 193(1): p. 47-54.
[8] Johnson, T.R., et al., *Material differentiation by dual energy CT: initial experience*. European radiology, 2007. 17(6): p. 1510-1517.
[9] Kruger, R., S.J. Riederer, and C. Mistretta, *Relative properties of tomography, K-edge imaging, and K-edge tomography*. Medical physics, 1977. 4(3): p. 244-249.
[10] Tawfik, A.M., et al., *Dual-energy CT of head and neck cancer: average weighting of low-and high-voltage acquisitions to improve lesion delineation and image quality—initial clinical experience*. Investigative radiology, 2012. 47(5): p. 306-311.
[11] Tawfik, A., et al., *Image quality and radiation dose of dual-energy CT of the head and neck compared with a standard 120-kVp acquisition*. American Journal of Neuroradiology, 2011. 32(11): p. 1994-1999.
[12] Wichmann, J.L., et al., *Virtual monoenergetic dual-energy computed tomography: optimization of kiloelectron volt settings in head and neck cancer*. Investigative radiology, 2014. 49(11): p. 735-741.
[13] Albrecht, M.H., et al., *Assessment of an advanced monoenergetic reconstruction technique in dual-energy computed tomography of head and neck cancer*. European radiology, 2015. 25(8): p. 2493-2501.
[14] Razak, H.R.A., S.M.S.S. Rahmat, and W.M.M. Saad, *Effects of different tube potentials and iodine concentrations on image enhancement, contrast-to-noise ratio and noise in micro-CT images: a phantom study*. Quantitative imaging in medicine and surgery, 2013. 3(5): p. 256.
[15] Boll, D.T., et al., *Renal stone assessment with dual-energy multidetector CT and advanced postprocessing techniques: improved characterization of renal stone composition—pilot study.* Radiology, 2009. 250(3): p. 813-820.

[16] Graser, A., et al., *Dual energy CT: preliminary observations and potential clinical applications in the abdomen.* European radiology, 2009. 19(1): p. 13.