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Original Article

Gemstone spectral imaging of coronary artery based on ASIR

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Abstract: *Background:* Gemstone spectral imaging (GSI) is able to produce dual energy with the aid of fast kilovoltage (kVp)-switching technique. The monochromatic images at energy levels ranging from 40 to 140 keV are able to be derived. Adaptive statistical iterative reconstruction (ASIR) can optimize image quality through reducing image noise. The optimal monochromatic energy levels for multiple tissues at different backgrounds have been preliminarily investigated. However, the influence of background, gender and body mass index (BMI) on the optimal monochromatic energy level for gemstone spectral imaging of coronary artery based on ASIR has not been reported yet. *Objectives:* To investigate the influence of background, gender and BMI on the optimal monochromatic energy level for GSI of the coronary artery based on ASIR. *Methods:* A total of 90 patients received dual-energy scan of GSI of the coronary artery. Raw data were reconstructed with ASIR. Muscle, fat and myocardium were selected as backgrounds, respectively. CT values and image noise were collected, which were used to calculate the optimal monochromatic energy levels for the left anterior descending (LAD), left circumflex (LCX) and right coronary artery (RCA). *Results:* The optimal monochromatic energy levels for LAD, LCX and RCA using muscle as background were not statistically different between male and female (66.43±0.93 vs 66.41±0.79 for LAD, 66.44±0.94 vs 66.46±0.84 for LCX, and 66.55±1.00 vs 66.54±0.84 for RCA). The optimal monochromatic energy levels for LAD, LCX and RCA using muscle as background were not statistically different between normal and overweight group (66.69±0.67 vs 66.48±1.00 for LAD, 66.73±0.78 vs 66.50±1.00 for LCX, and 66.85±0.62 vs 66.62±1.09 for RCA), but both of them were higher than in the obese group (vs 65.94±0.59 for LAD, vs 65.97±0.57 for LCX, and vs 65.97±0.63 for RCA). The optimal monochromatic energy levels for LAD, LCX and RCA showed the same trend of fat > muscle > myocardium (69.71±0.87 vs 66.68±0.70 vs 64.74±0.63 for LAD, 69.80±0.62 vs 66.67±0.65 vs 64.90±0.71 for LCX, and 69.64±0.70 vs 66.64±0.78 vs 64.96±0.60 for RCA). *Conclusions:* The separate background of ASIR and BMI had certain influence on the optimal monochromatic energy levels for LAD, LCX and RCA.

Keywords: Gemstone spectral imaging, optimal monochromatic energy level, coronary artery, background, body mass index, gender

Introduction

Polychromatic imaging in conventional CT causes averaging attenuation of CT values and reduces the image quality [1]. Gemstone spectral imaging (GSI) is able to produce dual energy with the aid of a fast kilovoltage (kVp)-switching technique [2]. The monochromatic images at energy levels ranging from 40 to 140 keV are able to be derived, which can eliminate averaging attenuation of CT values induced by polychromatic imaging [3]. However, the image quality at different energy levels varies. The image with the best quality can be acquired at the optimal monochromatic energy level, which has the optimal contrast-to-noise ratio (CNR) [4, 5]. Adaptive statistical iterative reconstruction (ASIR) can optimize image quality through reducing the image noise. Therefore, it is widely applied in spectral imaging. However, the separate background of ASIR may have an influence on the optimal monochromatic energy level. The optimal monochromatic energy levels for multiple tissues at different backgrounds have been preliminarily investigated, and the results show that they are different. Therefore, the influence of background, gender and body mass index (BMI) on the optimal monochromatic energy level for gemstone spectral imaging of coronary artery based on ASIR was investigated in this study.

Materials and methods

Participants

A total of 90 patients scheduled for CT coronary angiography were enrolled between January and April in 2016. They included 43 males and 47 females. The average was (53.0±6.8) years, (25.0±2.1) Kg/m^2 and (53.0±6.3)/min, respectively for age, BMI and heart rate. All patients received dual-energy scan with GSI. Raw data were reconstructed with ASIR. Muscle, fat and myocardium were selected as backgrounds, respectively. The patients were divided into male (n=43) and female (n=47) groups according to gender, as well as normal (18.5 kg/m^2<BMI<24 kg/m^2, n=30), overweight (24 kg/m^2≤BMI<28 Kg/m^2, n=39) and obese (BMI≥28 Kg/m^2, n=21) according to BMI. The optimal monochromatic energy levels for the left anterior descending (LAD), left circumflex (LCX) and right coronary artery (RCA) was determined with GSI Viewer software package.

Inclusion and exclusion criteria

The inclusion criteria of participants included (1) clinical suspected coronary heart disease patients; (2) a heart rate less than 65 beats/min; (3) no contraindications for enhanced scan; and (4) written informed consents. The exclusion criteria included (1) arrhythmia or a heart rate greater than 65 beats/min; (2) severe cardiac, hepatic and renal insufficiency; (3) allergic to contrast agents; and (4) obvious thyroidism or severe thyrotoxicosis.

CT scan protocol

Discovery CT 750HD (GE healthcare, Milwaukee, WI) was employed. A high-pressure injector with binocular tube (Ulrich, Germany) was used to inject the contrast agent (iopamidol 370 mgI/mL) via right upper extremity vein. CT values of the upper segment of the thoracic aorta were detected using contrast tracer technique. The threshold was set to 100 HU and monitored at a frequency of 1 time/sec. Scanning was triggered when the threshold was reached, ranging from 1 cm under bronchial bifurcation to 2 cm under cardiac base. Dual-energy GSI mode was employed with a fast tube voltage switching between 80 and 140 kVp. Scanning parameters included tube voltage period 0.25 ms, rotation speed 0.35 s/r, thickness 0.625 mm. All patients received a dosage of 0.8 mL/Kg of the contrast agent at an injection rate of 5 mL/s and a bonus of 20 mL of saline at the same injection rate after the contrast agent.

Image reconstruction

The 65 keV monochromatic images were reconstructed using ASIR. The reconstructed images were transferred to GE AW 4.6 station with GSI Viewer software package (GE Medical Systems, Waukesha, WI). Regions of interest (ROIs) were chosen in the LAD, LCX and RCA. ROIs should have areas as large as possible based on the actual condition and kept away from blood vessels and calcification. Muscle, fat and myocardium were selected as the background, at the same level as ROIs. The optimal monochromatic energy levels for the LAD, LCX and RCA at different backgrounds were then calculated. Each artery was measured 3 times and the average was obtained.

Statistical analysis

The SPSS 19.0 software (SPSS Inc., USA) was used to perform statistical analysis, and significance was set at *P*<0.05. Normality of data was evaluated with Kolmogorov-Smirnov test. Normal data were expressed as mean ± standard deviation (SD). Covariance analysis was employed to compare the optimal monochromatic energy level between male and female groups, as well as between normal, overweight and obese groups. One-way ANOVA was employed to compare the optimal monochromatic energy levels at different backgrounds, and Post Hoc Multiple Comparisons were performed with Student Newman Keuls method.

Results

Influence of gender on optimal monochromatic energy levels

The CT values and image noise of RCA using muscle as background in male and female are shown in **Figures 1** and **2**, these were used to

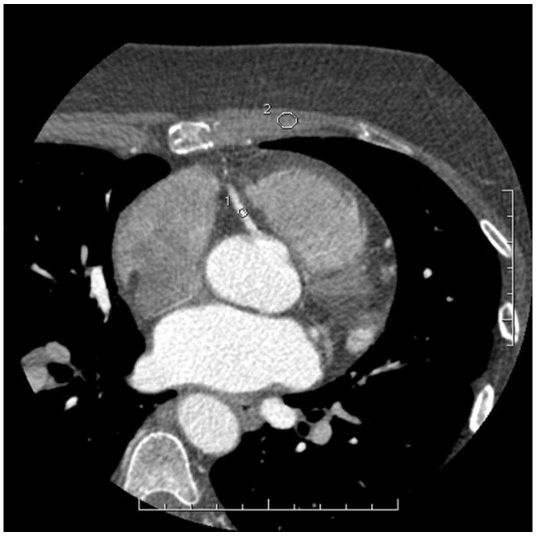

Figure 1. CT values and image noise of RCA using muscle as background, in a male 65 years old and with BMI of 29.2 Kg/m^2. (1) for RCA, and (2) for background.

Figure 2. CT values and image noise of RCA using muscle as background, in a female 60 years old, with BMI of 29.2 Kg/m^2. (1) for RCA, and (2) for background.

calculate the optimal monochromatic energy level.

Covariance analysis was performed using the optimal monochromatic energy level as dependent variable, gender as fixed factor and age, BMI and heart rate as covariates. The results demonstrated that the optimal monochromatic energy levels for LAD (66.43±0.93 vs 66.41± 0.79 keV), LCX (66.44±0.94 vs 66.46±0.84 keV) and RCA (66.55±1.00 vs 66.54±0.84 keV) using muscle as background were not statistically different between males and females (all P > 0.05). Therefore, gender had no influence on the optimal monochromatic energy levels for LAD, LCX and RCA.

Figure 3. CT values and image noise of RCA using muscle as background, in a male 51 years old and with a BMI of 23.4 Kg/m^2 (normal group). (1) for RCA, and (2) for background.

Influence of body mass index on optimal monochromatic energy levels

The CT values and image noise of RCA using muscle as background in normal, overweight and obese groups are shown in **Figures 3-5**, which were used to calculate the optimal monochromatic energy level.

Normal group included 12 males and 18 females, overweight group included 19 males and 20 females, obese group included 12 males and 9 females. The distribution of gender was not statistically different between normal, overweight and obese groups (P > 0.05). Covariance analysis was performed using the optimal monochromatic energy level as dependent variable, BMI grouping as fixed factor and age and heart rate as covariates. The results showed that the optimal monochromatic energy levels for LAD (66.69±0.67 vs 66.48±1.00 keV), LCX (66.73±0.78 vs 66.50±1.00 keV) and RCA (66.85±0.62 vs 66.62±1.09 keV) using muscle as background were not statistically dif-

Figure 4. CT values and image noise of RCA using muscle as background, in a male 60 years old and with BMI of 26.4 Kg/m^2 (weight group). (1) for RCA, and (2) for background.

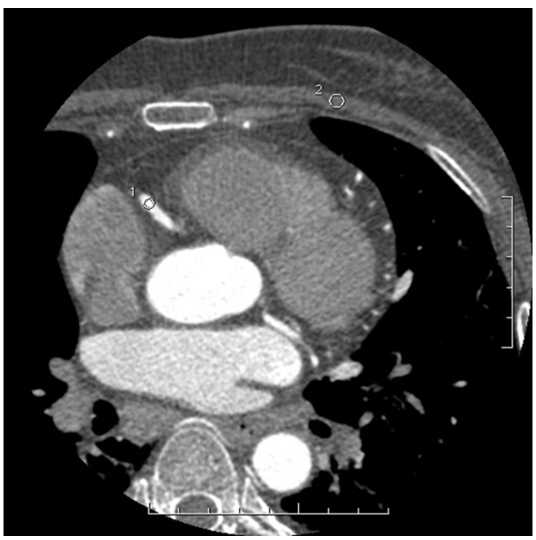

Figure 5. CT values and image noise of RCA using muscle as background, in a female 58 years old and with BMI of 30.1 Kg/m^2 (obese group). (1) for RCA, and (2) for background.

ferent between normal and overweight group (all $P > 0.05$). However, the optimal monochromatic energy levels for LAD (66.69±0.67 vs 65.94±0.59 keV), LCX (66.73±0.78 vs 65.97±0.57 keV) and RCA (66.85±0.62 vs 65.97±0.63 keV) using muscle as background were significantly higher in the normal than in the obese group (all $P<0.05$), and the optimal monochromatic energy levels for LAD (66.48±1.00 vs 65.94±0.59 keV), LCX (66.50±1.00 vs 65.97±0.57 keV) and RCA (66.62±1.09 vs 65.97±0.63 keV) using muscle as background were also significantly higher in the overweight than in the obese group (all $P<0.05$). Therefore, BMI had a certain influence on optimal monochromatic energy levels for LAD, LCX and RCA.

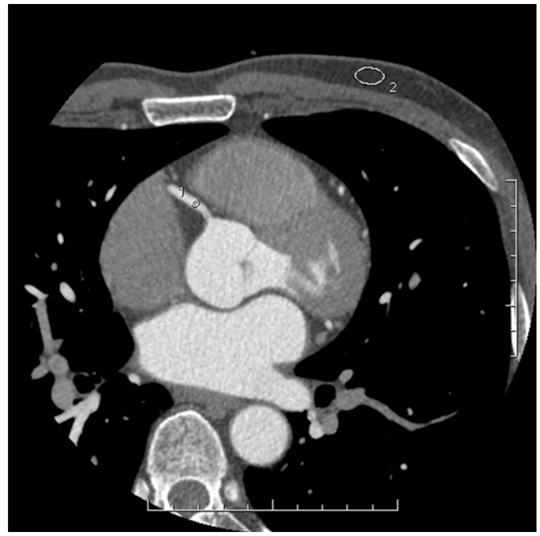

Figure 6. CT values and image noise of RCA of a male 49 years old and BMI of 25.2 Kg/m^2 using fat as background. (1) for RCA, and (2) for background.

Influence of background on optimal monochromatic energy levels

The CT values and image noise of RCA based on different backgrounds are demonstrated in **Figures 6-8**, and were used to calculate the optimal monochromatic energy level.

According to the results of one-way ANOVA, the optimal monochromatic energy levels for LAD (69.71±0.87 vs 66.68±0.70 vs 64.74±0.63 keV), LCX (69.80±0.62 vs 66.67±0.65 vs 64.90±0.71 keV) and RCA (69.64±0.70 vs 66.64±0.78 vs 64.96±0.60 keV) showed the same significant trend of fat > muscle > myocardium (all $P<0.05$). Therefore, background had a certain influence on optimal monochromatic energy levels for LAD, LCX and RCA.

Discussion

GSI can obtain 101 monochromatic images at energy levels ranging from 40 to 140 keV, and the image with the optimal CNR provides the best image quality. The corresponding energy

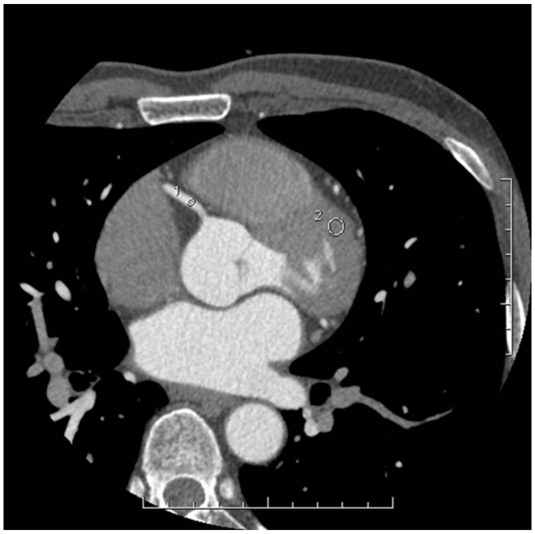

Figure 7. CT values and image noise of RCA of a male 49 years old and BMI of 25.2 Kg/m^2 using myocardium as background. (1) for RCA, and (2) for background.

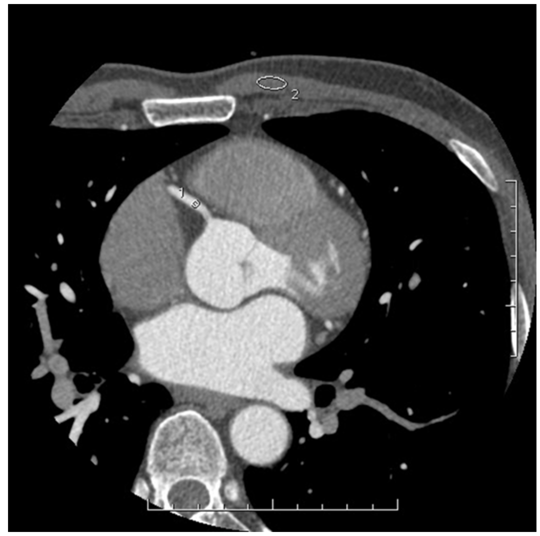

Figure 8. CT values and image noise of RCA of a male 49 years old and BMI of 25.2 Kg/m^2 using muscle as background. (1) for RCA, and (2) for background.

level is the optimal monochromatic energy level. Monochromatic images have been widely applied in clinical practice, including diagnosing tumors, analyzing urinary calculi, displaying abdominal vessels and so on [6-9]. The optimal monochromatic energy levels for multiple tissues at different backgrounds have been reported.

Jia et al, [10] investigated the application of GSI in a multi-parameter quantitative measurement of lung cancer using the same ROI in the thoracic aorta as background. Their results demonstrated that the optimal monochromatic energy level for displaying lung cancer on plain scan, arterial phase and venous phase was 62.2±5.38 keV, 50.63±3.84 keV, and 52.5±3.7 keV, respectively. Yu et al, [11] investigated the application of GSI and ASIR in pediatric abdominal CT patients with solid tumors. Their results showed that the optimal monochromatic energy level was 40 keV for displaying abdominal vessels. Lin et al, [12] investigated the application of GSI in the brain. Their results showed that the optimal monochromatic energy level for displaying brain parenchyma was 70 keV, which could significantly reduce the beam-hardening artifacts and image noise. Ohana et al, [13] reconstructed monochromatic images every 5 keV from 40 to 140 keV in lung window of spectral CT for analyzing the lung parenchyma. Their results demonstrated that the 50-55 keV monochromatic reconstructions provided the best diagnostic and image quality. Yu et al, [14] used CT spectral imaging to differentiate hepatocellular carcinoma from focal nodular hyperplasia. Their results demonstrated that CT spectral imaging might be helpful in enhancing accuracy of differentiating hepatocellular carcinoma from focal nodular hyperplasia and detectability of lesions, and the low monochromatic energy levels (40-70 keV) provided higher CNRs compared to the high energy levels (80-140 keV). Lv et al, [8] used spectral CT to derive monochromatic images at energy levels from 40 to 140 keV and conventional 140-kVp polychromatic images in patients with small HCC (≤3 cm). Their results showed that the monochromatic energy levels of 40, 50 and 70 keV provided monochromatic images with the highest CNRs. The monochromatic energy level of 70 keV provided the lowest image noise for monochromatic images, which had higher image quality compared to conventional polychromatic images. They concluded that the monochromatic energy levels (40-70 keV) can enhance detectability of small HCC, which might not cause the degradation of image quality.

Several reconstruction techniques are introduced in order to improve the image quality of CT examination. Filtered back projection (FBP) technique is traditionally a principal method, but it is unable to reduce radiation dose significantly [15-17]. Iterative reconstruction can not only minimize image noise but also reduce radiation dose remarkably [18]. ASIR is the first-generation iterative reconstruction technique and uses information derived from the FBP algorithm as an initial building block for image reconstruction [19]. ASIR is better than FBP in reducing noise and artifact due to incapability of FBP in taking into account system noise and certain system hardware details including detector sizes, location and actual focal spot [20, 21]. ASIR has been widely applied in spectral CT and acknowledged the potential in reducing image noise [22-25]. Especially for images at low monochromatic energy levels, ASIR can reduce their image noise [26]. In this study, 40% ASIR was employed to reconstruct monochromatic images and achieved good effects (**Figures 1-8**).

The influence of background, gender and body mass index (BMI) on the optimal monochromatic energy level for GSI of coronary artery based on ASIR has not been reported yet. In our study, the optimal monochromatic energy levels for LAD, LCX and RCA using muscle as background were not statistically different between male and female (66.43±0.93 vs 66.41±0.79 for LAD, 66.44±0.94 vs 66.46±0.84 for LCX, and 66.55±1.00 vs 66.54±0.84 for RCA); the optimal monochromatic energy levels for LAD, LCX and RCA using muscle as background were not statistically different between normal and overweight group (66.69±0.67 vs 66.48±1.00 for LAD, 66.73±0.78 vs 66.50±1.00 for LCX, and 66.85±0.62 vs 66.62±1.09 for RCA), but both of them were higher than obese group (vs 65.94±0.59 for LAD, vs 65.97±0.57 for LCX, and vs 65.97±0.63 for RCA); the optimal monochromatic energy levels for LAD, LCX and RCA showed the same trend of fat > muscle > myocardium (69.71±0.87 vs 66.68±0.70 vs 64.74±0.63 for LAD, 69.80±0.62 vs 66.67±0.65 vs 64.90±0.71 for LCX, and 69.64±0.70 vs 66.64±0.78 vs 64.96±0.60 for RCA). Therefore, gender had no influence on the optimal monochromatic energy levels for LAD, LCX and RCA of the coronary artery, but BMI and background had certain influence on the optimal monochromatic energy levels for LAD, LCX and RCA. In summary, BMI and background had certain influence on the optimal monochromatic energy levels for LAD, LCX and RCA.

This study had three main limitations. The first was that we failed to collect patients with BMI≤ 18.5 Kg/m^2 due to the small sample. The second was that the influence of age on the optimal monochromatic energy level was not investigated for the same reason. The third was that we only used 40% ASIR in this study. In the next investigative step, we will conduct a larger sample size study and ascertain the influence of different ASIR percentages on the optimal monochromatic energy level.

Disclosure of conflict of interest

None.

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