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The optimal monochromatic spectral computed tomographic imaging plus adaptive statistical iterative reconstruction algorithm can improve the superior mesenteric vessel image quality

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ABSTRACT

Objective: To investigate the effect of the optimal monochromatic spectral computed tomography (CT) plus adaptive statistical iterative reconstruction on the improvement of the image quality of the superior mesenteric artery and vein.
Materials and methods: The gemstone spectral CT angiographic data of 25 patients were reconstructed in the following three groups: 70 KeV, the optimal monochromatic imaging, and the optimal monochromatic plus 40%iterative reconstruction mode. The CT value, image noises (IN), background CT value and noises, contrast-to-noise ratio (CNR), signal-to-noise ratio (SNR) and image scores of the vessels and surrounding tissues were analyzed.
Results: In the 70 KeV, the optimal monochromatic and the optimal monochromatic images plus 40% iterative reconstruction group, the mean scores of image quality were 3.86, 4.24 and 4.25 for the superior mesenteric artery and 3.46, 3.78 and 3.81 for the superior mesenteric vein, respectively. The image quality scores for the optimal monochromatic and the optimal monochromatic plus 40% iterative reconstruction groups were significantly greater than for the 70 KeV group ($P < 0.05$). The vascular CT value, image noise, background noise, CNR and SNR were significantly ($P < 0.001$) greater in the optimal monochromatic and the optimal monochromatic images plus 40% iterative reconstruction group than in the 70 KeV group. The optimal monochromatic plus 40% iterative reconstruction group had significantly ($P < 0.05$) lower image and background noise but higher CNR and SNR than the other two groups.
Conclusion: The optimal monochromatic imaging combined with 40% iterative reconstruction using low-contrast agent dosage and low injection rate can significantly improve the image quality of the superior mesenteric artery and vein.

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1. Introduction

Multislice spiral computed tomography angiography (MSCTA) has become a fast, non-invasive screening method to evaluate abdominal vascular disease because it can clearly show the superior mesenteric artery (SMA) and the superior mesenteric vein (SMV) lumen and anatomical changes for the diagnosis of the superior mesenteric artery syndrome, dissection and acute mesenteric ischemia with high specificity [1–5]. For the diagnosis of mesenteric ischemia disease, MSCTA is able to show the morphology of the mesenteric artery and vein as well as the intestinal wall changes in the conventional contrast enhancement, significantly better than the conventional digital subtraction angiography examination [6]. The key to improving the image quality of CTA is to increase the contrast between blood vessels and surrounding tissues, and it was achieved previously by increasing the flow rate or doses of the contrast agent or the X-ray doses, which would increase the radiation dose, adverse reactions and risk of contrast extravasation. It has become a hot academic research to improve the image quality of blood vessels while decreasing the radiation and contrast agent doses.

The latest MSCT systems like dual-source computed tomography (DSCT), dual-energy computed tomography (DECT) and

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sandwich detector DECT scanners can address the above problems. The sandwich detector DECT introduces the concept of dual layer (sandwich) detectors to clinical CT devices, with an x-ray spectrum having a constant tube voltage irradiating a detector comprising two scintillator layers. The upper lay detects the low energy part of the spectrum while the lower layer detects the high energy part being prefiltered by the layer above [7]. The DSCT scanner has two x-ray tubes using different kVp (80 and 140 kVp), whereas the DECT imaging can be achieved by a single x-ray tube with fast kilovolt dynamic switching between two different energy levels of x-rays from view to view during a single rotation [7]. The DECT is capable of distinguishing different materials at high density (for example, separating iodinated contrast from other materials), whereas beam-hardening artifacts usually resulting from polychromatic energy of x-ray spectrum can be eliminated with use of the monochromatic energy images spectrum [7]. Spectral computed tomography (CT), a dual energy CT technology with fast kilovoltage switching, can sample two sets of data by instantaneous switching between two peak voltage settings (80 and140 kVp) in less than 0.5 ms to generate 101 different monochromatic CT images at multiple kilo-electron voltages (KeV) in the range of 40–140 KeV [8]. These two data sets obtained from the two different energies permit reconstruction of material decomposition images to synthesize monochromatic images which simulate images as if different monochromatic x-ray sources were utilized. The optimal contrast monochromatic image between vessels and surrounding tissues can be obtained by application of the contrast-to-noise ratio (CNR) curve. Iterative reconstruction algorithm has been incorporated into the monochromatic image set to reduce the image noise effectively and take full advantage of the increased contrast over the low energy range. The outstanding feature of iterative reconstruction is to achieve the best image density resolution by using an iterative computing technology to significantly reduce noise and improve image quality [9,10]. Currently, no studies have been performed on improvement of the mesenteric vascular image quality by concurrent use of optimal monochromatic spectral CT imaging and iterative reconstruction. This article used the optimal monochromatic CT imaging and iterative reconstruction to improve the mesenteric vascular image quality compared to conventional single energy spectral CT images.

2. Materials and Methods

2.1. Subjects

This study was approved by the hospital ethics committee for scientific research and all patients had provided signed informed consent to participate. Twenty-five patients were enrolled to undergo abdominal enhanced scan with spectral CT in the first two months of 2016. There were 14 male and 11 female patients, with an age range of 45 74 years (mean 59.48 ± 8.34), including 6 cases of liver cyst, 3 liver cancer, 3 liver hemangioma, 4 liver metastases, 4 renal cysts, 1 splenic cyst, 1 pancreatic cancer, 2 gastric cancer, and 1 gallbladder cancer. The height, weight, body mass index (BMI) and body surface area (BSA) of these patients were 165.7 ± 6.76 (150–176) m, 67 ± 8.0 (54–84) kg, 24.5 ± 3.7 (18.7–35.6) kg/m^2 and 1.7 ± 0.1 (1.52–1.95) m^2, respectively.

2.2. Scanning protocol

The contrast enhanced spectral CT scanning of the Gemstone spectral imaging was performed from diaphragm to the edge of the anterior superior iliac crest with a spectral CT scanner (Discovery CT 750 HD, GE Healthcare, Milwaukee, WI, USA) which can instantaneously switch between two peak tube voltages (80 and 140 kVp) in 0.5 ms. The spectral CT scan protocol included mAs 375, pitch 0.984:1, gantry rotation time 0.5 s, slice thickness and spacing 5 mm, reconstruction thickness 1.25 mm, and field of view (FOV) 50 cm × 50 cm. The contrast agent used was ioversol (320 mg Iodine/mL) with the injection rate of 3.5 ml/s in the amount of 1.0 ml/kg. An automatic tracking technique was used to initiate the scan at the trigger threshold (120 Hounsfield units) at the level of the celiac trunk for the arterial phase, whereas the portal venous phase and later delay phase scanning were started 30 s and 120 s after the initiation of the arterial phase, respectively.

2.3. Imaging reconstruction and grouping

The images of the arterial and venous phases were reconstructed at 70 KeV, optimal monochromatic imaging, and optimal monochromatic imaging plus 40% adaptive statistical iterative reconstruction (ASIR, GE Healthcare) corresponding sequence imaging. In the 70 KeV Group, the images of the arterial and portal venous phases (without iterative reconstruction) were transferred to the GE ADW (4.6) workstation for analysis. The CT values of the superior mesenteric artery and vein and the sacrospinal muscle at the same slice at the 70 KeV energy point were measured, and the CNR and signal-to-noise ratio (SNR) were calculated. In the optimal monochromatic group, the sets of images obtained at 70 KeV were analyzed to get the optimal CNR curve for the superior mesenteric artery and vein and the sacrospinal muscle at the same level (Fig. 1). Based on the optimal CNR curve, the optimal KeV values were calculated for measuring the CT values of the superior mesenteric artery and vein and the sacrospinal muscle, and the CNR and SNR were evaluated. In the optimal monochromatic images plus 40% iterative reconstruction group, the reconstructed arterial and venous phase spectrum images plus 40% iterative reconstruction images were transmitted to the GE ADW (4.6) workstation to obtain the optimal monochromatic images plus 40% iterative reconstruction for the superior mesenteric artery and vein, and the CT values of the superior mesenteric artery and vein and the sacrospinal muscle at the same slice were calculated with the corresponding SNR and CNR evaluated.

The region of interest (ROI) of the above three images was selected at the same position. The sequences of images of the superior mesenteric artery and vein in the above three groups were reconstructed with volume rendering (VR), maximum intensity projection (MIP) and multiplanar reconstruction (MPR).

2.4. Image evaluation

A circular ROI with areas ranging from 15 mm^2 to 20 mm^2 was placed on the superior mesenteric artery or vein and the sacrospinal muscle at the same level to measure the mean CT values. The same size of ROI was used to measure the superior mesenteric vessels and the sacrospinal muscle, and each point was measured 3 times to get the mean value. The CT values of the background were also evaluated at the sacrospinal muscle. The SNR was evaluated as the mean CT value of ROI divided by the mean image noise, whereas the CNR was assessed as the mean CT value of vessel minus CT value of background muscle divided by the mean image noise of vessel, based on the following formula: $CNR = (ROIo - ROId)/SDn$ and $SNR = ROIo/SDn$, where ROIo indicates the CT value of the superior mesenteric artery or vein, ROId denotes the CT value of the sacrospinal muscle at the same slice, and SDn denotes the mean background image noise. The sacrospinal muscle was used as the contrast tissue.

Two radiologists each with 8 years and 15 years of experience in radiological imaging performed qualitative assessment separately on a workstation with dedicated software (Gemstone Spectral Imaging Viewer, GE, USA). The evaluation was in a blinded

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