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FULL PAPER

Clinical value of dual-energy spectral imaging with adaptive statistical iterative reconstruction for reducing contrast medium dose in CT portal venography: in comparison with standard 120-kVp imaging protocol

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Objective: To evaluate the clinical value of dual-energy spectral CT with adaptive statistical iterative reconstruction (ASiR) for reducing contrast medium dose in CT portal venography (CTPV).

Methods: This prospective study was institutional review board-approved, and written informed consent was obtained from all patients. 50 patients undergoing abdominal CT were randomized to 2 groups: Group A ($n = 25$), using spectral CT and 350 mgI kg^{-1} contrast injection protocol; Group B ($n = 25$), using standard 120 kVp and 500 mgI kg^{-1} contrast. Spectral CT images at 60 keV and standard 120-kVp images were both reconstructed with 50% ASiR. CT number and contrast-to-noise ratio (CNR) for intrahepatic and extrahepatic portal veins were measured. The maximum intensity projection (MIP) and volume-rendering (VR) images were used for subjective evaluation. These two kinds of results were statistically analyzed.

Results: CNR values for the intrahepatic portal vein of the 60-keV spectral images (4.2 ± 1.1) were higher than

those of 120-kVp images (3.0 ± 2.1) ($p = 0.03$) and were the same for the extrahepatic portal vein (5.9 ± 1.4 vs 5.9 ± 1.6 , $p = 0.90$). The portal vein and left and right branches in the 60-keV spectral images had higher CT number and lower standard deviation than the 120-kVp images ($p < 0.05$). Radiation dose (dose-length product and effective dose) and subjective image quality were similar for the two groups, while the spectral CT group required 25% less iodine dose ($23.1 \pm 3.2 \text{ g}$ vs $30.5 \pm 5.0 \text{ g}$).

Conclusion: The 60-keV spectral CT images with ASiR allow 25% reduction in the iodine dose while providing better or equal image quality as the standard 120-kVp images in portal venography with comparable radiation dose.

Advances in knowledge: Compared with conventional 120-kVp CT, the use of 60-keV spectral CT images provides 25% contrast dose reduction with similar image quality in CTPV. Compared with conventional 120-kVp CT, the use of 60-keV spectral CT images with ASiR algorithm improves CNR values for the intrahepatic portal vein.

INTRODUCTION

Multislice spiral CT portal venography (CTPV) is now being widely used as a non-invasive, economic and fast method for portal venous imaging.¹ Because portal venous imaging is reflux venous-phase imaging, a relatively high contrast dose is used in standard CTPV to ensure adequate contrast for displaying the portal veins. However, the use of high contrast dose may produce toxic effects. Recently, there has been a lot of effort to reduce the total iodine load to patients and has been demonstrated in CT pulmonary angiography (CTPA) with the use of low-tube-voltage and dual-energy scanning technique.^{2–4} Dual-energy spectral CT has also been used in

CTPV with standard contrast dose to improve the contrast-to-noise ratio (CNR) for displaying the hepatic portal veins.⁵ The purpose of this study was to compare the quantitative and subjective image quality between the conventional 120-kVp CTPV with standard iodine dose and dual-energy spectral CTPV with adaptive statistical iterative reconstruction (ASiR) with reduced iodine dose.

METHODS AND MATERIALS

Study groups

This prospective study was institutional review board-approved, and written informed consent was obtained

from all patients. From January to April 2014, 50 patients undergoing abdominal CT (28 males, 22 females) were randomized into 1 of the 2 CTPV protocol groups: dual-energy CTPV group (Group A, $n = 25$) or standard CTPV group with 120-kVp tube voltage (Group B, $n = 25$). The average patient ages were 58.9 ± 12.3 years and 52.6 ± 10.2 years in Group A and Group B, respectively. The patients included 10 cases of liver lipoma, 15 cases of liver cyst, 12 cases of hepatic haemangioma, 2 cases of hepatic adenoma, 8 cases of gallbladder stones and 3 cases with negative findings. The inclusion criteria were: (1) age more than 18 years; (2) no severe heart, kidney and vascular diseases affecting the blood supply to the liver; (3) normal liver function; (4) no indications of malignant liver lesions or other malignant lesions affecting the hepatic arterial and venous blood flow; and (5) images free of motion and metal artefacts.

CT scans

All patients were scanned on a GE Discovery CT750HD scanner in the feet-first supine position. Patients were asked to drink 500 ml of warm water twice (5 min apart) before the CT scan. The scan range was from 2 cm above the diaphragm to the bottom of the kidneys. For patients in Group A, CTPV was acquired with the single-tube, dual-voltage (80 kVp and 140 kVp) fast-switching spectral CT imaging mode. Since dual-energy spectral CT has only a fixed set of scan protocols to choose from, we selected the spectral CT scan protocol that produced a similar CT dose index (CTDI) as the standard 120-kVp imaging (noise index was set at 10 HU at 5-mm image slice thickness for the standard 120-kVp scan) for the patient in the dual-energy spectral CT group. A non-ionic contrast agent (Ultravist 370, Bayer Healthcare Ltd., Guangzhou, China) was used with an iodine load of 350 mgI kg^{-1} for patients in Group A. For patients in Group B, the standard scan protocol with 120 kVp was used with the standard contrast dose of 500 mgI kg^{-1} . The tube current was automatically adjusted by the scanner to achieve an image noise of 10 HU at 5-mm image thickness. The contrast medium was injected *via* the antecubital venous access by using a dual-tube power injector (Ulrich, German). The injection time was fixed at 25 s, and the injection rate was adjusted according to the total contrast volume. Contrast injection was followed by 20 ml of saline at the same injection rate. The portal venous-phase scan started 65 s after the injection of the contrast medium. Other scanning parameters for both the spectral CT and standard CT were: collimation: $0.625 \text{ mm} \times 64$; scan field of view (SFOV): 50 cm; rotation speed: 0.8 s^{-1} helical pitch: 1.375:1. Volumetric CTDI and dose-length product values were recorded. Effective dose was calculated using the conversion factor of $0.015 \text{ mSv mGy}^{-1} \text{ cm}^{-1}$.⁶

Image processing and data analysis

Images were reconstructed with a standard reconstruction kernel at a thickness of 1.25 mm. The ASiR algorithm with 50% strength was used. For the dual-energy spectral CT image reconstruction, only the 60-keV virtual monochromatic images were selected for comparison. Both the 60-keV virtual monochromatic image set and 120-kVp polychromatic image set were transferred to an AW4.6 workstation for measurement and analysis. For objective evaluation, a circular region of interest (ROI) was placed in the main portal vein and left and right branches at the level of 2 cm

from the bifurcation to measure the CT number and its standard deviation (SD). The same parameters for the erector spinae and liver parenchyma at the same image level were also measured. ROI covered the central 75% of the vessel area. For liver parenchyma, areas of focal change in parenchymal density, large vessels and prominent artefacts were carefully avoided. The CNR for vessels was calculated using the following equation: $\text{CNR} = (\text{ROI}_o - \text{ROI}_d) / \text{SD}_n$, where ROI_o and ROI_d represent the CT number of the portal vein and liver parenchyma, respectively, and SD_n is the SD of the erector spinae.

For subjective image quality evaluation, multiplanar maximum intensity projection (MIP) and volume-rendering (VR) images were used for a three-dimensional display of the vascular system for the portal veins, including the trunk and branches of the portal vein, superior mesenteric vein and splenic vein. Two attending physicians (XT and YJJ with 4 and 6 years' experience, respectively, in CT abdominal imaging) blinded to the imaging protocol subjectively evaluated the two groups of images.

Subjective evaluation was carried out in two areas: the number of segmental branches observed and image quality scoring for how well the vessels were displayed. For the number of segmental branch observation, each additional segmental level added 1 to the final score. For the image quality score, a 5-point score system was used to include the vessel enhancement, edge sharpness, segmental level vessel clarity and image noise: (1) poor opacification and unclear edge resulting in images which are non-diagnostic, major noise in image; (2) suboptimal opacification and unclear edge resulting in low confidence in making the diagnosis, high noise; (3) limited opacification and somewhat fuzzy edge but sufficient for diagnosis, moderate noise; (4) good opacification to the segmental level with clear edge for confident diagnosis, minor image noise; (5) excellent opacification to the segmental level with sharp edge for full confident diagnosis, minimum image noise. The final global image quality score was determined by averaging the two reader scores. Discordance for interpretability was discussed between the two readers to reach consensus. Image quality scores of 2 and below were considered non-diagnostic.

Statistical method

Quantitative variables were reported as mean $\pm$ SD. The differences of the quantitative variables such as patient age and body mass index (BMI), total iodine dose, CTDI, dose-length product and effective dose values, vessel enhancement and CNR values between the two groups were evaluated with two-tailed *t*-test (independent sample). The subjective evaluation was compared with the Mann-Whitney *U*-test between the two groups. Analyses were performed by using SPSS17.0 statistical software. A statistically significant difference was defined at a *p*-value < 0.05 .

RESULTS

The patient demographics, iodine dose and radiation dose of the CT scans are listed in Table 1. There was no significant difference in age, BMI and weight between the two groups (all $p > 0.05$). There was also no significant difference in the effective dose between the dual-energy CTPV protocol ($5.8 \pm 1.9 \text{ mSv}$) and standard 120-kVp protocol ($6.2 \pm 2.1 \text{ mSv}$) ($p = 0.58$). On the

Table 1. Patient characteristics, X-ray dose and contrast medium volume

Parameter	Spectral CTPV (<i>n</i> = 25)	Standard CTPV (<i>n</i> = 25)	<i>T</i> value	<i>p</i> -value
Patient characteristic				
Female: male	11:14	11:14		
Age (years)	58.9 ± 12.3	52.6 ± 10.2	1.38	0.12
BMI (kg m ⁻²)	24.5 ± 2.9	24.4 ± 1.9	0.01	0.57
Weight (kg)	65.4 ± 8.9	59.2 ± 10.1	-2.03	0.06
X-ray dose				
CTDIvol (mGy)	10.4 ± 4.0	13.1 ± 2.3	-1.68	0.12
DLP (mGy cm ⁻¹)	387.5 ± 128.7	410.1 ± 141.9	-0.55	0.58
Effective dose (mSv)	5.8 ± 1.9	6.2 ± 2.1	-0.55	0.58
Contrast medium volume				
Total iodine (g)	23.1 ± 3.2	30.5 ± 5.0	3.6	<0.001

BMI, body mass index; CTDIvol, volumetric CT dose index; CTPV, CT portal venography; DLP, dose-length product.

other hand, the dual-energy CTPV protocol had 25% lower iodine load than the standard CTPV protocol (23.1 ± 3.2 g vs 30.5 ± 5.0 g, *p* < 0.001).

The signal intensity was higher and image noise was lower in the dual-energy CTPV images than in the standard 120-kVp images in the portal vein (187.2 ± 16.2 HU vs 152.8 ± 19.2 HU for enhancement and 16.5 ± 3.3 HU vs 19.6 ± 2.3 HU for noise comparison), right branch (193.4 ± 16.9 HU vs 155.5 ± 19.3 HU and 16.0 ± 3.5 HU vs 19.0 ± 3.3 HU) and left branch (190.0 ± 14.7 HU vs 156.0 ± 21.3 HU and 15.9 ± 3.0 HU vs 18.4 ± 2.2 HU) (all *p* < 0.05) (Table 2). CNR values (4.2 ± 1.1) for the intrahepatic portal vein of the 60-keV spectral images were higher than those of the 120-kVp images (3.0 ± 2.1) (*p* < 0.05) and were the same for the extrahepatic portal vein (5.9 ± 1.4 vs 5.9 ± 1.6, *p* = 0.90) (Table 2). The 60-keV virtual monochromatic images of spectral CT imaging demonstrated

higher contrast enhancement and CNR for the intrahepatic portal veins than those of the CTPV imaging, even though the image quality scores were not significantly different (4.5 ± 0.6 vs 4.4 ± 0.7, *p* = 0.41). Dual-energy CTPV protocol also allowed the observation of more left and right branches of the portal veins with scores for the number of observed segmental vessel levels being 5.2 ± 1.0 and 5.0 ± 1.0, respectively, vs the 4.1 ± 0.2 and 4.2 ± 0.7 for the standard CTPV protocol (Figures 1, 2 and Table 3).

DISCUSSION

In this study, we evaluated the clinical value of dual-energy spectral CT with ASiR for reducing contrast medium dose in CTPV. Our study has shown that the dual-energy spectral CTPV protocol allowed for 25% reduction in iodine contrast dose, compared with a standard CTPV protocol, while improving the intravascular signal intensity in the portal veins and reducing

Table 2. Comparison of quantitative measurements of spectral CT portal venography (CTPV) and standard CTPV protocols

Parameter	Spectral CTPV (<i>n</i> = 25)	Standard CTPV (<i>n</i> = 25)	<i>T</i> value	<i>p</i> -value
Signal intensity (HU)				
Portal vein	187.2 ± 16.2	152.8 ± 19.2	7.94	<0.001
Right branches	193.4 ± 16.9	155.5 ± 19.3	7.66	<0.001
Left branches	190.0 ± 14.7	156.0 ± 21.3	5.71	<0.001
Noise				
Portal vein	16.5 ± 3.3	19.6 ± 2.3	-3.24	<0.001
Right branches	16.0 ± 3.5	19.0 ± 3.3	-2.49	0.02
Left branches	15.9 ± 3.0	18.4 ± 2.2	-3.01	<0.001
CNR				
Intrahepatic portal veins	4.2 ± 1.1	3.0 ± 2.1	2.25	0.03
Extrahepatic portal veins	5.9 ± 1.4	5.9 ± 1.6	-0.79	0.90

CNR, contrast-to-noise ratio.

Figure 1. (a, b) A 40-year-old, 45-kg female patient with a 35 × 42-mm haemangioma in the right hepatic lobe (arrows). The volume-rendering (a) and maximum intensity projection (b) images were generated with the dual-energy spectral CT imaging mode and 350-mgIkg⁻¹ iodine concentration. The portal venous system is clearly displayed and the lesion in the portal venous phase shows progressive enhancement with a clear boundary.

image noise. Dual-energy spectral CTPV also improved or maintained CNR for the hepatic portal veins, at a comparable estimated radiation dose. Subjective image quality scores between the two CTPV protocols were statistically the same. Dual-energy spectral CTPV protocol also allowed for the observation of significantly more portal vein branches with scores for the number of observed segmental vessel levels of 5.2 ± 1.0 for the left branches and 5.0 ± 1.0 for the right branches compared with corresponding scores of 4.1 ± 0.2 and 4.2 ± 0.7 for the standard CTPV protocol. We have selected the 25% contrast dose reduction to be conservative for the preliminary study. We speculate that further contrast dose reduction is possible considering the fact that at 25% contrast dose reduction, dual-energy spectral CT at 60 keV still produced higher CT numbers in the portal veins than conventional CT at full contrast dose. Further studies are required to fully explore the contrast dose-reduction potential.

Because portal venous imaging is reflux venous-phase imaging, a relatively high contrast dose is used in standard CTPV to ensure adequate contrast for displaying the portal veins. However, the potential risk of intravenous contrast material-induced nephrotoxicity is thought to be a limitation of CTPV, particularly in patients with borderline renal function. Low-tube-voltage scanning has been used to reduce contrast

medium dose in CTPA.^{4,7} However, there is an inherent limitation with this technique, particularly when imaging the abdominal area where there is more attenuation or when attempting to evaluate non-vascular structures in patients with a higher BMI.⁷ The recently introduced dual-energy spectral CT imaging mode has also been applied in clinical practice for either reducing contrast dose in CTPA² or improving image quality at the standard contrast dose level in CTPV.⁵ Using a single-source dual-energy system with rapid tube-voltage switching between 80 and 140 kVp, the dual-energy spectral CT imaging mode allows the acquisition of high- and low- kilovoltage peak projections simultaneously and produces 101 sets of virtual monochromatic images with photon energy levels from 40 keV to 140 keV. The work by Zhao et al⁵ found that an energy level of around 50 keV was the best energy level for achieving the highest CNR for displaying the hepatic portal veins. Their work also indicated that at that energy level, image noise was also increased compared with the standard imaging technique. In our study, we found that the optimal photon energy actually happened around 60 keV (Figure 3) (58.5 ± 1.7 keV); so, we chose an energy level of 60 keV for comparison, which is closer to the average energy level of 80-kVp imaging to facilitate iodine dose reduction. One other reason for selecting this specific energy level was because in our scanner, the ASiR algorithm works only for energy levels that are higher than 60 keV. Our study suggested that the use of ASiR greatly reduced image noise and the 60-keV energy

Table 3. Comparison of qualitative evaluation of spectral CT portal venography (CTPV) and standard CTPV protocols

Parameter	Spectral CTPV (<i>n</i> = 25)	Standard CTPV (<i>n</i> = 25)	Z value	<i>p</i> -value
Number of left branches observed	5.2 ± 1.0	4.1 ± 0.2	-0.88	0.37
Number of right branches observed	5.0 ± 1.0	4.2 ± 0.7	-0.92	0.35
Subjective image quality	4.5 ± 0.6	4.4 ± 0.7	-0.83	0.41

Figure 2. (a, b) A 37-year-old male, 51kg, with gallstones. Volume-rendering and maximum intensity projection images were generated with the standard CT portal venography protocol of 120 kVp and 500-mgIkg^{-1} iodine concentration. The portal vein system is clearly displayed, but the edges are less sharp than those in Figure 1.

level provided a good balance between increased image signal intensity and increased image noise for imaging body areas with substantial attenuation such as the abdomen. This new imaging technique allows iodine dose reduction in CTPV because the signal intensity drop due to the reduced iodine load is compensated by the increased enhancement resulting from the lower energy at which the images were reconstructed, and the image noise is further reduced by the use of ASiR, which further improves CNR for the portal veins. The

dual-energy CTPV protocol with ASiR used in our study showed that despite the significantly lower contrast dose in the dual-energy CTPV protocol ($23.1 \pm 3.2\text{ g}$ vs $30.5 \pm 5.0\text{ g}$), the signal intensity was higher and image noise was lower in the dual-energy spectral CTPV images than in the standard 120-kVp images in the portal vein (Table 1). Furthermore, the increased enhancement in the vascular systems and reduced image noise did not come at the expense of radiation dose. The effective dose value for the dual-energy

Figure 3. (a, b) Contrast-to-noise (CNR) ratio of the hepatic portal vein as a function of photon energy demonstrating that the optimal energy level is close to 60 keV.

spectral CTPV protocol (5.8 ± 1.9 mSv) was statistically the same as the standard 120-kVp CTPV protocol (6.2 ± 2.1 mSv) ($p = 0.58$).

Our study has several limitations. First, this investigation reflects our preliminary experience with a small number of patients who had normal liver functions. Further investigations are needed to include more patients and patients with diseases that affect liver functions and vascular functions. Second, this work mainly focused on the quantitative and qualitative image criteria while it did not include the diagnostic accuracy of liver diseases in terms of sensitivity and specificity according to a reference standard. Further studies are needed to validate the clinical advantage of

dual-energy spectral CTPV for tumour detection and characterization. Finally, consensus readings were used in this study for measurement and image evaluation. Therefore, we did not present the interobserver variability.

In conclusion, the 60-keV spectral CT images with ASiR allow 25% reduction in iodine dose with comparable radiation dose while providing better or equal image quality as the standard 120-kVp images in CTPV.

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