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FULL PAPER

Automatic spectral imaging protocol and iterative reconstruction for radiation dose reduction in typical hepatic hemangioma computed tomography with reduced iodine load: a preliminary study

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Objective: To evaluate the effect of automatic spectral imaging protocol selection (ASIS) and adaptive statistical iterative reconstruction (ASiR) technique in the reduction of radiation and contrast medium dose in typical hepatic hemangioma (HH) dual energy spectral CT (DEsCT).

Methods: 62 patients with suspected HH were randomly divided into two groups equally: Group A, conventional 120-kVp CT with standard iodine load; Group B, DEsCT with ASIS technique and reduced iodine load, two sets of monochromatic spectral images were reconstructed: 69 keV level with 30% ASiR (Group B₁) and 52 keV level with 50% ASiR (Group B₂). The radiation and total iodine dose, quantitative analysis (standard deviation value, contrast-to-noise and contrast enhancement ratio) and qualitative analysis were evaluated.

Results: No difference was observed in the standard deviation values, subjective image noise, and the diagnostic acceptability score among the three groups ($p > 0.05$). Contrast to noise [Group B₂ vs A, B₁ in arterial phase (AP): 19.51 ± 6.29 vs 15.77 ± 5.93 , 11.46 ± 2.84 ; Group B₂ vs A, B₁ in portal venous phase (PVP): 9.96 ± 2.18 vs 8.19 ± 3.04 , 6.01 ± 1.82], contrast enhancement

ratio (Group B₂ vs A, B₁ in AP: 6.88 ± 2.01 vs 5.47 ± 2.01 , 4.15 ± 1.28 ; Group B₂ vs A, B₁ in PVP: 5.58 ± 1.02 vs 4.54 ± 1.13 , 3.49 ± 0.83), and the lesion conspicuity score (Group B₂ vs A, B₁ in AP: 3.93 ± 0.26 vs 3.45 ± 0.51 , 3.10 ± 0.49 ; Group B₂ vs A, B₁ in PVP: 3.90 ± 0.31 vs 3.48 ± 0.57 , 3.14 ± 0.44) for Group B₂ were higher than those in Group A and B₁ ($p < 0.05$). Compared to Group A, the radiation dose and total iodine dose in Group B were reduced by 30 and 41%, respectively (radiation dose in Group B vs A: 5.53 ± 1.59 vs 7.91 ± 2.71 mSv; iodine dose in Group B vs A: 18.85 ± 2.88 vs 31.78 ± 3.89 ml; $p < 0.05$).

Conclusion: DEsCT with ASIS and ASiR technique can reduce the radiation dose without image quality degradation as compared to the conventional 120-kVp CT. The monochromatic spectral images at 52 keV level with 50% ASiR allows the reduction in total iodine dose without deteriorating diagnostic performance.

Advances in knowledge: ASIS combined with ASiR technique, by using monochromatic spectral images at 52 keV level, represents a feasible imaging protocol to reduce the radiation and total iodine dose in assessment of typical HH.

INTRODUCTION

In the past two decades, contrast-enhanced CT is widely used in clinical practice. However, contrast-enhanced CT can increase the potential risk of radiation exposure-induced carcinogenesis and contrast agent-induced acute kidney injury, especially in patients with a chronic clinical course who need to undergo repeated multiphase CT examinations.¹ Thus, a trend towards low-iodine load

and low-radiation dose (termed “double low”) is imminent. Sigal-Cinqualbre et al² firstly hypothesized that the low-tube voltage scanning might facilitate the reduction in iodine load by enhancing the vasculature, owing to the lower effective energy is closer to the K-edge (33.2 keV) of iodine. Presently, the low-tube voltage combined with low-iodine concentration contrast medium (CM) could reduce the radiation dose and iodinated CM dose.^{3–5} However, in the

case of obese patients with high body mass index (BMI), the reduction in tube voltage can dramatically increase image noise due to photon starvation. In addition, the reduced penetration of X-ray photons at a low-tube voltage tends to accentuate the streak artifacts caused by beam hardening adjacent to highly attenuated structures.^{6,7} Compared to the low-tube voltage in conventional CT imaging, dual energy spectral CT (DEsCT) with the fast kilo-voltage switching between 140 and 80 kVp allows the reconstruction of monochromatic images with selectable X-ray energy (40–140 keV) to optimize the image contrast resolution.^{8–10} However, the application of DEsCT has been impeded because of relatively high-radiation exposure in the initial clinical practice.^{11,12} Subsequently, Shuman et al¹³ confirmed that the appropriately selected imaging parameters presented that the radiation dose of DEsCT was equivalent to that in conventional CT scanning mode. Recently, a CT manufacturer implemented an automatic spectral imaging protocol selection (ASIS) technique, a commercial software tool [Gemstone spectral imaging (GSI) Assist, GE Healthcare, Waukesha, WI] that automatically determines the optimal spectral imaging protocol based on the patient size (absorption path length) determined during the anteroposterior and lateral scout views and the preset target non-spectral imaging noise index (NI). Research have shown that spectral imaging can improve the visibility of contrast-enhanced blood vessels, thereby reduce the required amount of iodinated CM.^{14,15} To the best of our knowledge, no correlative study is yet available on “double low” hepatic DEsCT. The present study evaluated the effect of ASIS and adaptive statistical iterative reconstruction (ASiR) algorithm technique in the reduction of radiation and CM dose in typical hepatic hemangioma (HH) DEsCT. Moreover, the dose and image quality were compared to those in conventional 120-kVp CT.

METHODS AND MATERIALS

Patients

This prospective randomized study was approved by the institutional review board of our hospital (Qianfoshan Hospital Affiliated to Shandong University, Jinan, China), and written informed consent was obtained from all patients. A total of 75 patients with suspected HH, based on the findings of previous ultrasonography, were screened for eligibility for enrollment in the present study from October 2016 to May 2017. The inclusion criteria of the patients were as follows: BMI ≥ 20 kg m⁻² but ≤ 30 kg m⁻². The maximum diameter of each lesion was >1 cm; the patients did not present any history of hepatic cirrhosis and malignant tumor. The exclusion criteria were as follows: patients with renal failure (glomerular filtration rate <30 ml min⁻¹ 1.73 m⁻²), history of anaphylactic reaction, pregnant, and age <18 years. A total of 13 patients were excluded from this study due to the following: a history of anaphylactic reaction ($n = 5$), renal dysfunction ($n = 6$), and refusal to provide informed consent ($n = 2$). Finally, 62 patients (24 males, 38 females; mean age, 42.6 years; age range, 23–63 years) were included in this study. In addition, weight, height, and BMI of patients were recorded.

Scanning protocol and CM injection

All patients underwent hepatic multiphase CT examinations on a 64-row multidetector CT system (Discovery CT, GE Healthcare,

Milwaukee, WI). The CT examinations consisted of one non-enhanced phase (NP) and three contrast-enhanced phases: arterial phase (AP), portal venous phase (PVP), and equilibrium phase (EP). The scanning range encompassed the diaphragmatic dome to lower poles of both kidneys in all phases. 31/62 enrolled patients were randomly assigned to Group A, the conventional 120-kVp scanning protocol with NI = 10.0, and automatic tube current modulation technique was used in all phases. The other 31 patients were assigned to Group B, in the NP, the same 120-kVp scanning protocol was used in the three contrast-enhanced phases, and DEsCT with ASIS technique was performed.

ASIS was designed to automatically recommend the optimal spectral scanning protocol using a target non-GSI NI value as the reference. In conventional CT imaging, the tube current is modulated by the selection of NI and patient size. However, in spectral CT imaging, a list of scanning protocols with fixed tube current and rotation time are provided. Given a target non-GSI NI value as the reference, ASIS calculates the volume CT dose index (CTDIvol) based on the target non-GSI NI, patient size, scan parameters, scan range,¹⁶ and recommends the optimal preset GSI protocol with CTDIvol similar to that by a non-GSI acquisition mode.

The basic workflow of ASIS used in this study was as follows: (1) two initial scout views (anteroposterior and lateral) were obtained. (2) ASIS was turned on, and GSI preset menu was refined or filtered based on user preference and clinical task for the anatomic region, rotation time, scan field of vision, and detector coverage. (3) A target non-GSI NI was defined in the GSI preset menu. The target NI was set as 13 for Group B, slightly higher than that used in Group A such that the target CTDIvol was lower than the routine 120-kVp scanning mode.

Group A received high-iodine concentration CM (Iopamiro370, Iopamidol injection, Bracco, Shanghai, China) with standard iodine load (450 mgI kg⁻¹), while Group B was administered iso-osmotic low-iodine concentration CM (Visipaque 270, Iodixanol injection, GE Healthcare, WI) with low iodine load (270 mgI kg⁻¹). The iodine delivery rate (IDR) was calculated for each patient using the following formula: IDR (mgI s⁻¹) = CM concentration (mgI ml⁻¹) $\times$ injection flow rate (ml s⁻¹). The CM was delivered via a 20 or 18G catheter inserted into a right median cubital vein using a dual-channel power injector (Ulrich Medical, Germany), at an injection flow rate of 4 mls⁻¹ for all cases, followed by a 30 ml saline flush at the same rate.

Bolus tracking (Smart-Prep software, GE Healthcare) technique was used in the AP for each patient, with the monitoring region of interest (ROI) being placed on the abdominal aorta at the level of the first hepatic portal and a triggering threshold of 150 HU. The AP scanning was initiated at 5.6 s after the attenuation in the monitoring ROI, which reached the triggering threshold. The PVP was started at 30 s after the completion of the AP, and the EP started at 300 s after the end of the PVP. The scanning and CM injection parameters were described in Table 1. The BMI and

Table 1. Scanning and contrast medium injection parameters in Groups A and B

Parameters	A	B
Tube voltage (kVp)	120	80 and 140
Tube current control	ATCM	ASIS
Tube current range (mA)	150–650	260–640
Gantry rotation time (s)	0.7	0.5–1.0
Pitch	1.375:1	1.375:1
NI (HU)	10	13
Detector coverage (mm)	40	40
Reconstruction algorithm	ASiR	ASiR
Section/interval thickness (mm)	5/5	5/5
Reconstructed section/interval thickness (mm)	1.25/1.25	1.25/1.25
Iodine concentration (mgI ml ⁻¹)	370	270
Iodine load (mgI kg ⁻¹)	450	270
Iodine delivery rate (gI s ⁻¹)	1.48	1.08

ASiR, adaptive statistical iterative reconstruction; ASIS, automatic spectral imaging protocol selection; CM, contrast medium; NI, Noise index; ATCM, automatic tube current modulation.

numbers of patients corresponding to each GSI preset protocol were shown in Table 2.

Image reconstruction

The Group A data were reconstructed with 30% ASiR to serve as the reference standard. Two sets of monochromatic spectral images from Group B data were reconstructed on the CT console: 69 keV level with 30% ASiR (Group B₁) and 52 keV level with 50% ASiR (Group B₂). A previous study^{17–20} and our clinical experience suggested that monochromatic spectral level at 69 keV yields images resembling conventional those at 120kVp, and the 52keV level was selected as it showed the highest lesion-to-liver-contrast-to-noise (CNR).

Quantitative image analysis

The CT images in the NP, AP, and PVP were assessed on an independent workstation (Advantage workstation 4.6, GE Healthcare). The quantitative image analysis was performed by a radiologist with 8 years of clinical experience in abdominal CT imaging. The lesion number and size (maximum diameter) were recorded. The CT values in the HH lesions were measured by manually placing the circular or elliptical ROIs that were drawn to encompass a maximal high-enhancing portion of the lesion distally from the discernible vessels or artifacts during the AP and PVP. In addition, a circular ROI of approximately 150 mm² was placed in the homogeneous area of normal hepatic parenchyma at the same image-level as HH lesion, and calcification, vessels, or bile ducts were carefully avoided. In the NP, the HH ROIs of identical size were placed in the same image sections and positions as in the AP and PVP. The mean CT value and standard deviation (SD) in the ROI were recorded. All quantitative measurements were performed three times at three consecutive image sections, and the averages obtained. The lesion-to-hepatic parenchyma CNR and lesion contrast enhancement ratio (CER) were calculated using following formulae:

$$\text{CNR} = (\text{ROI}_{\text{lesion contrast enhanced}} - \text{ROI}_{\text{liver}}) / \text{SD}_{\text{liver}} \quad (1)$$

Where $\text{ROI}_{\text{lesion contrast enhanced}}$ and $\text{ROI}_{\text{liver}}$ refer to the mean CT values of the HH lesion and adjacent normal hepatic parenchyma in the AP and PVP, respectively. SD_{liver} is the mean image noise defined by the SD value for circular ROI placed in a homogeneous region of the normal hepatic parenchyma in the AP and PVP.

$$\text{CER} = (\text{ROI}_{\text{lesion contrast enhanced}} - \text{ROI}_{\text{lesion NP}}) / \text{ROI}_{\text{lesion NP}} \quad (2)$$

Where $\text{ROI}_{\text{lesion NP}}$ refer to the mean CT value of the HH lesion in the NP.

Table 2. The BMI and number of patients corresponding to GSI preset protocols

Preset protocol	CTDIvol (mGy)	Tube current (mA)	Gantry rotation time(s)	n ^a	BMI ^b
GSI-48	6.48	260	0.7	2 (6.5)	20.59 (20.14–21.04)
GSI-54	6.52	275	0.6	2 (6.5)	22.42 (22.4–22.45)
GSI-44	7.64	275	0.7	1 (3.2)	22.3
GSI-40	8.79	360	0.6	2 (6.5)	23.99 (22.49–25.5)
GSI-31	9.25	375	0.6	3 (9.7)	23.61 (21.33–25.30)
GSI-22	10.76	375	0.7	13(42)	26.00 (24.45–29.86)
GSI-1	12.72	630	0.5	3 (9.7)	27.47 (26.23–28.73)
GSI-27	16.87	550	0.8	1 (3.2)	29.08
GSI-10	18.28	600	0.8	3 (9.7)	29.25 (28.45–29.74)
GSI-4	20.71	600	0.9	1 (3.2)	30

BMI, body mass index, CTDIvol, volume CT dose index; GSI, gemstone spectral imaging.

^aNumbers of patients corresponding to each preset protocol, values in parentheses are percentages.

^bData are the means with BMI ranges in parentheses.

Qualitative image analysis

The image quality was assessed independently by two radiologists (Observer 1 and Observer 2, with 8 and 17 years of professional experience in abdominal CT diagnostics, respectively) using a preset abdominal window setting [window width, 400 Hounsfield unit (HU); window level, 40 HU] at the AW4.6 workstation; the window setting could be varied as necessary. Both observers were blinded to the patients' information (weight, BMI), CM type, and scan parameters. The image quality was graded according to the subjective image noise, lesion conspicuity, and diagnostic acceptability using a 4-point subjective scale. The subjective image noise score was defined as follows: Score 1, excessive image noise and artifacts, poor definition of anatomical structures; Score 2, high image noise and artifacts, suboptimal definition of anatomical structure; Score 3, moderate image noise and artifacts, good definition of anatomical structure; Score 4, minimal image noise and artifacts, excellent definition of anatomical structures. The typical HH lesion appears as well-defined low-density NP, contrast enhancement showing peripheral nodular or globular enhancement similar to the adjacent abdominal aorta in the AP, and progressive centripetal homogeneous filling in the PVP and EP. The non-enhanced intralesional spots could occur due to fibrosis, thrombosis, or necrosis. Lesion conspicuity score: Score 1, inconspicuous, barely detectable; Score 2, mild finding but likely a lesion; Score 3, definite lesion detected; Score 4, obvious finding and easily detected. Diagnostic acceptability score: Score 1, inferior; Score 2, average; Score 3, above average; Score 4, superior.

Radiation dose and total iodine dose evaluation

CTDIvol and dose-length product (DLP, mGy·cm) in the PVP were recorded for each patient. The DLP was converted to the estimated effective radiation dose (ED, mSv) by multiplying by the standard conversion factor of $0.015 \text{ mSv} \times \text{mGy}^{-1} \text{cm}^{-1}$ for abdominal CT imaging.²¹ Furthermore, the radiation dose produced by the two different scanning modes in the same patient was evaluated by comparing the CTDIvol, DLP, and ED between the NP and PVP in group B. The total iodine dose for each patient was also recorded.

Statistical analysis

All statistical analyses were performed using the SPSS software package (IBM SPSS Statistics v. 22®; Chicago, IL). The numeric data were expressed as mean $\pm$ SD, while the categorical data were summarized as counts and proportions. The gender composition, number, and sex distribution for the lesions between groups A and B were compared using the χ^2 test (Fisher's exact), while the independent sample *t*-test determined the difference in patient and lesion characteristics, radiation dose, and total iodine dose. The mean CT value, SD, CNR, and CER were analyzed by one-way analysis of variance. Subjective image noise, lesion conspicuity, and diagnostic acceptability score were evaluated using the Wilcoxon signed rank test. The Bonferroni correction was used for all the multiple comparisons. $p < 0.05$ was considered as statistically significant. The interobserver agreement for qualitative image analysis was assessed using Cohen's κ test, and the κ -value was defined as follows: <0.20 , poor; 0.2 – 0.40 , fair; 0.41 – 0.60 , moderate; 0.61 – 0.80 , good; and 0.81 – 1.00 , excellent.

Table 3. The patients and lesion characteristics in groups A and B

Characteristics	A	B	<i>p</i> -value
Gender composition (M/F)	11/20	13/18	0.669
Age (years)	42.25 $\pm$ 13.22	42.96 $\pm$ 14.10	0.586
Weight (kg)	69.55 $\pm$ 8.73	70.86 $\pm$ 8.30	0.754
BMI (kg m ⁻²)	25.38 $\pm$ 2.64	25.63 $\pm$ 2.65	0.720
Lesion number/sex distribution	31 (M: 10; F: 21)	29 (M: 12; F: 17)	0.466
Size (cm)	4.12 $\pm$ 2.51	3.98 $\pm$ 2.72	0.687

Data are mean $\pm$ standard deviation. BMI, body mass index; F, female; M, male.

No significant differences was detected between the two groups in the patients and lesion Characteristics ($p > 0.05$).

RESULTS

Patient and lesion characteristics

A total of 62 patients in groups A and B were successfully scanned. 29 out of 31 patients in Group A exhibited 31 HH lesions (two patients had two lesions), with 10 lesions found in male patients, and 21 lesions in female patients; and 29 HH lesions were recorded in 29 out of 31 patients in Group B, with 12 lesions in male patients and 17 in female patients. These were confirmed based on the histological findings ($n = 21$) and typical imaging features ($n = 39$). However, no significant differences were noted in the patient age, gender composition, weight, BMI, size, or sex-based distribution of the lesion between the two groups (Table 3).

Quantitative image analysis

The mean CT values of lesions in the NP for groups A and B were 35.82 ± 5.92 HU and 34.93 ± 6.82 HU, respectively. The mean CT values of the normal hepatic parenchyma in the AP for groups A, B₁, and B₂ were 65.59 ± 5.62 , 63.80 ± 4.12 , and 71.55 ± 2.49 HU, and in the PVP 100.73 ± 12.08 , 94.72 ± 10.06 , and 130.56 ± 20.87 HU, respectively. No significant differences were noted in the SD values of the normal hepatic parenchyma among the three groups during the AP and PVP ($p > 0.05$). The mean CT values of the lesion, CNR, and CER for Group B₂ were significantly higher than those in groups A and B₁ ($p < 0.05$) during the AP and PVP; furthermore, a similar phenomenon was observed between groups A and B₁ ($p < 0.05$), as shown in Table 4.

Qualitative image analysis

The results of the qualitative image assessment and interobserver agreement test in the AP and PVP were summarized in Table 5. The interobserver agreement between the two radiologists was good (κ -value = 0.65 – 0.95), and no significant difference was noted in the subjective image noise and diagnostic acceptability score among the three groups ($p > 0.05$). The lesion conspicuity score for Group A was significantly higher than that for Group B₁ (3.42 ± 0.50 vs 3.17 ± 0.38 , $p < 0.05$), and that for Group B₂ was significantly higher than that in groups A and B₁ ($p < 0.05$) (Figures 1 and 2).

Table 4. Quantitative analysis comparison among the three groups during the AP and PVP

AP PVP											
Group		CT value (HU)	SD (HU)	CNR	CER	CT value (HU)	SD (HU)	CNR	CER		
A		224.95 ± 57.32	10.68 ± 2.38	15.77 ± 5.93	5.47 ± 2.01	192.68 ± 31.84	10.11 ± 1.50	8.19 ± 3.04	4.54 ± 1.13		
B ₁		174.73 ± 19.22	10.32 ± 2.03	11.46 ± 2.84	4.15 ± 1.28	154.97 ± 17.81	10.09 ± 1.85	6.01 ± 1.82	3.49 ± 0.83		
B ₂		265.71 ± 51.58	10.88 ± 2.70	19.51 ± 6.29	6.88 ± 2.01	215.46 ± 13.31	10.24 ± 1.65	9.96 ± 2.18	5.58 ± 1.02		
<i>p</i> -value	A vs B ₁	<0.001	1.000	0.006	0.018	<0.001	0.288	0.002	<0.001		
	A vs B ₂	0.016	0.727	0.022	0.010	0.002	0.433	0.017	<0.001		
	B ₁ vs B ₂	<0.001	1.000	<0.001	<0.001	<0.001	1.000	<0.001	<0.001		

AP, arterial phase; CER, contrast enhancement ratio; CNR, contrast-to-noise ratio; HU, Hounsfield unit; PVP, portal venous phase; SD, standard deviation.

Radiation dose and total iodine intake

The CTDIvol, DLP, ED, and total iodine dose for groups A and B were shown in Figure 3. Significant differences were observed between groups A and B with respect to CTDIvol (19.31 ± 4.11 vs 11.27 ± 3.68), DLP (528.49 ± 181.10 vs 368.00 ± 104.83), ED (7.91 ± 2.71 vs 5.53 ± 1.59), and total iodine dose (31.78 ± 3.89 vs 18.85 ± 2.88). The mean reduction rate of the CTDIvol, DLP, ED, and total iodine dose in Group B were 42, 30, 30, and 41%, respectively. In addition, significant differences were observed in the CTDIvol (19.02 ± 3.88 vs 11.27 ± 3.68), DLP (532.91 ± 175.33 vs 368.00 ± 104.83), and ED (8.00 ± 2.64 vs 5.53 ± 1.59) between the NP and PVP in Group B ($p < 0.001$); the mean reduction rate in the PVP was 41, 31, 31%, respectively.

DISCUSSION

Currently, MRI is deemed superior over CT imaging for confirming HH without any ionizing radiation. However, in daily practice, multiphase CT continues to play a major role in HH diagnosis, because of its affordable costs, high availability, short scanning times, and an acceptable sensitivity and specificity. With the dramatically increased clinical application of contrast-enhanced CT, the potential risks of high radiation and iodine dose also increases gradually.^{22,23} In the case of DEsCT, selecting the optimal dose-efficient spectral scanning protocol in daily clinical practice is rather challenging. Recently, ASIS technique was used to automatically select the DEsCT protocol based on the target non-spectral imaging NI and patient size. Lv et al¹⁶ did not report any significant difference in ED between DEsCT with ASIS technique and conventional 120-kVp CT. To the best of our knowledge, any previous study has not reported using “double low” DEsCT in the abdominal solid organ. Liu et al²⁴ reported that in comparison to conventional 120-kVp CT, spectral CT imaging significantly reduced the radiation dose in abdominal CT angiography for patients with high BMI using a fixed GSI preset protocol with 375 mA as tube current. However, one limitation of that study was that the same protocol was used in all patients, and individualized GSI preset protocol was not investigated. The ASIS technique could individualize the GSI scanning parameters based on the target non-spectral imaging NI to obtain a lower CTDIvol than the conventional 120-kVp CT. Our results confirmed that based on the target non-spectral imaging NI = 13.0, the radiation dose in DEsCT with ASIS technique was significantly reduced as compared to that in conventional 120-kVp CT with NI = 10.0. Furthermore, radiation dose from the same patient was compared between the non-GSI NP and GSI PVP in group B for an accurate evaluation of the radiation dose between conventional 120-kVp CT and DEsCT with ASIS technique.

The monochromatic spectral images are less susceptible to beam-hardening artifact and can potentially provide an accurate and reproducible attenuation measurements by decreasing the pseudoenhancement artifact.¹¹ In this study, the monochromatic spectral images at 69 keV level exhibit a similar image noise as conventional 120-kVp CT images; however, the radiation dose was significantly reduced, in agreement with previous studies.^{18,19} However, due to the low IDR and concentration of CM used in Group B, the CT value of the lesion, CNR, CER,

Table 5. Qualitative analysis comparisons among the three groups during the AP and PVP

AP PVP							
Group		Subjective image noise	Lesion conspicuity	Diagnostic acceptability	Subjective image noise	Lesion conspicuity	Diagnostic acceptability
A		3.39 ± 0.56	3.45 ± 0.51	3.52 ± 0.51	3.35 ± 0.61	3.48 ± 0.57	3.57 ± 0.51
B ₁		3.48 ± 0.57	3.10 ± 0.49	3.41 ± 0.50	3.45 ± 0.57	3.14 ± 0.44	3.45 ± 0.50
B ₂		3.41 ± 0.82	3.93 ± 0.26	3.62 ± 0.49	3.38 ± 0.56	3.90 ± 0.31	3.59 ± 0.52
<i>p</i> -value	A vs B ₁	0.480	0.011	0.431	0.564	0.009	0.602
	A vs B ₂	0.839	<0.001	0.418	0.926	0.001	0.589
	B ₁ vs B ₂	0.621	<0.001	0.118	0.620	<0.001	0.297
κ -value		0.74–0.80	0.65–0.93	0.76–0.94	0.81–0.93	0.78–0.95	0.71–0.89

AP, arterial phase; PVP, portal venous phase. Data are means $\pm$ standard deviation. $p < 0.05$ was considered to be statistically significant.

and lesion conspicuity score of Group B₁ (69 keV) was inferior to those of the 120 kVp images. Nevertheless, this inferiority can be overcome using a low monochromatic energy level. Thus, low monochromatic energies can improve iodinated CM attenuation owing to the increased X-ray absorption of iodine by raising the photoelectric effect.²⁵ This phenomenon substantially improves the conspicuity and detection ability of hyper- and hypovascular solid organ lesions based on the superior contrast resolution between the lesion and the surrounding normal tissue.^{6,25} The current study revealed that in comparison

to 120 kVp images, the monochromatic images at 52 keV level presented higher CT values of the lesion, CNR, CER, and lesion conspicuity while reducing 41% of the total iodine dose.

With the reduction in X-ray photon flux, the image noise at low monochromatic energy level increased gradually. As a compensation, ASiR selectively identified and reduced the image noise depending on a mathematic model and statistical iteration of raw CT data.²⁶ Presently, the ASiR technique has become a routine clinical practice instead of the conventional filtered back

Figure 1. Transverse typical HH CT images with the same window width, window level, and slice thickness obtained in a 39-year-old female with BMI 26.12 kg m^{-2} and 450 mgI kg^{-1} iodine load and in a 46-year-old female with BMI 25.86 kg m^{-2} and 270 mgI kg^{-1} iodine load (arrow). (a) Conventional 120-kVp image with 30% ASiR in the AP; (b) conventional 120-kVp image with 30% ASiR in the PVP; (c) monochromatic spectral image with 30% ASiR at 69keV level in the AP; (d) monochromatic spectral image with 30% ASiR at 69 keV level in the PVP; (e) monochromatic spectral images with 50% ASiR at 52 keV level in the AP; (f) monochromatic spectral image with 50% ASiR at 52 keV level in the PVP. The lesions conspicuity score for the monochromatic spectral image at 52 keV level (e, f) was significantly higher than those in the monochromatic image at 69 keV level (c, d) and conventional 120-kVp image (a, b) during the AP and PVP. AP, arterial phase; ASiR, adaptive statistical iterative reconstruction; BMI, body mass index; HH, hepatic hemangioma; PVP, portal venous phase.

Figure 2. Transverse typical HH CT images with the same window width, window level, and slice thickness obtained in a 47-year-old male with BMI 28.65 kg m^{-2} and in a 36-year-old female with BMI 27.49 kg m^{-2} and 270 mgI kg^{-1} iodine load (arrow). (a, b), -Conventional 120-kVp image with 30% ASiR in the AP and the PVP; (c, d), monochromatic spectral image with 30% ASiR at 69 keV level in the AP and the PVP; (e, f), monochromatic spectral images with 50% ASiR at 52 keV level in the AP and the PVP. The lesions conspicuity score for the monochromatic spectral image at 52 keV level (e, f) was significantly higher than those in the monochromatic image at 69 keV level (c, d) and conventional 120-kVp image (a, b). AP, arterial phase; ASiR, adaptive statistical iterative reconstruction; BMI, body mass index; HH, hepatic hemangioma; PVP, portal venous phase.

Figure 3. A box and whisker plot indicating the radiation dose and total iodine dose between conventional 120-kVp CT (Group A and NP in Group B) and DEsCT imaging (PVP in Group B). (a) CTDI_{vol}; (b) DLP; (c) ED; (d) total iodine dose. *indicates $p < 0.001$, significant differences in the CTDI_{vol}, DLP, ED, and total iodine dose were observed between groups A and B ($p < 0.001$); moreover, radiation dose comparison results from the same patient were detected between NP and PVP in group B ($p < 0.001$). AP, arterial phase; ASiR, adaptive statistical iterative reconstruction; CTDI_{vol}, volume weighted CT dose index; DEsCT, dual energy spectral CT; DLP, -length product; ED, non-enhanced phase; PVP, portal venous phase.

projection algorithm. Based on the recommendations of the manufacturer and our practical experience, ASiR weighting was set at 30% in the conventional 120-kVp CT and monochromatic spectral image at 69 keV level; moreover, 50% ASiR weighting in monochromatic spectral image at 52 keV level was based on previous study^{17,27} and the current phantom experiment. Low monochromatic energy images coupled with 50% ASiR weighting can effectively suppress the increased image noise due to the lack of photon flux. Herein, no significant difference was observed in the SD values and subjective image noise score between the monochromatic spectral images with 50% ASiR at 52 keV level (Group B₂) and those in groups A and B₁. Thus, excessive ASiR weighting can lead to artificial oversmoothing CT image such as “plastic” and “waxy” texture.^{28,29}

The present study has several limitations. First, the number of patients in each group was small. *Post-hoc* power analysis showed that, while the effect size of all the other significant comparisons was close to or larger than 0.8 (0.79 ~ 0.99), the effect size for CNR in AP and PVP was 0.67 and 0.75, respectively. Thus, further studies with a large number of patients are needed. Second, for DEsCT imaging, only NI = 13.0 was selected, and the effects of other NI were not evaluated. Third, only patients with BMI ranging from 20 to 30 were included, and the abdominal perimeter size of the patients was not considered. In comparison to the low-tube voltage technique, the protocol adopted in the current study eliminated the potential problem of photon starvation, in addition, image noise and beam hardening can be largely

offset by selecting appropriate ASiR and monochromatic energy level during image reconstruction, thereby the current protocol provides a promising application on obese patients. The primary goal of the current study was to verify this protocol works on normal-size patients, the subsequent study should be performed on patients with other BMIs. Fourth, only relatively large hemangioma (>1 cm) were included, additional studies are needed to examine how the technique used in the current study work for small lesions. Finally, additional studies are essential to compare the DEsCT with ASIS to low-tube voltage technique in hepatic parenchyma lesions.

In conclusion, ASIS technique is useful in reducing the radiation dose in abdominal DEsCT without image quality degradation. The application of the monochromatic spectral images at 52 keV level coupled with 50% ASiR could significantly reduce the image noise without deteriorating the diagnostic performance for conspicuity and detection of typical HH and allowing the reduction in total iodine dose without compromising the image contrast.

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