Original Article

Feasibility of low-dose contrast media in run-off CT angiography on dual-layer spectral detector CT

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Background: The aim of the present study was to assess the feasibility of applying low-dose contrast media (CM), and to explore the optimal virtual monoenergetic images (VMIs) in run-off computed tomography (CT) angiography (CTA) on dual-layer spectral detector CT (SDCT).

Methods: Forty patients were randomly assigned into a control group using routine volume CM (group A) and an experimental group using half-volume CM (group B). In groups A and B, 120 kVp polychromatic conventional images were generated via hybrid iterative reconstruction algorithm defined as A1 and B1, respectively. Additionally, in group B, VMIs (range, 40–120 keV) were reconstructed via a spectral reconstruction algorithm defined as B2–B10. Vascular attenuation, noise, signal-to-noise ratio (SNR), contrast-to-noise ratio (CNR), and radiation dose were evaluated. Subjective evaluation was performed using a 5-point scale.

Results: The patient demographics and radiation dose demonstrated no significant difference between groups A and B [dose length product (DLP): 1,823.45±512.68 *vs.* 2,014.40±453.25 mGy·cm, P=0.229; volume CT dose index: 14.92±3.40 *vs.* 16.26±2.85 mGy, P=0.208; the effective dose (ED): 10.82±3.02 *vs.* 11.88±2.67 mSv, P=0.229]. The mean vascular attenuation was higher in group B2 (40 keV) and was lower in group B3 (50 keV) in comparison with that in group A1 (487.07±154.21 *vs.* 414.35±71.66 HU, 329.90±100.25 *vs.* 414.35±71.66 HU, P>0.05). Compared with group A1, the mean noise was similar in group B2 (40 keV) and was lower in group B1 and groups B3–B10 (50–120 keV) (14.81±5.67 *vs.* 17.29±4.70 HU, P>0.05; 6.75±1.23–11.26±3.24 *vs.* 17.29±4.70 HU, P<0.05). The mean SNR and CNR in group B2 (40 keV), as well as the mean SNR in group B3 (50 keV), were significantly higher than those of group A1 (38.21±7.52 *vs.* 28.25±7.20, 32.70±7.79 *vs.* 24.54±6.60, 32.85±7.10 *vs.* 28.25±7.20, P<0.05), and the mean CNR in group B3 (50 keV) was similar to that in group A1 (26.66±7.32 *vs.* 24.54±6.60, P>0.05). Scores of subjective image quality (IQ) in group B2 (40 keV) and B3 (50 keV) were similar to those in group A1 {5 [4.25, 5] *vs.* 5 [4, 5], 5 [5, 5] *vs.* 5 [4, 5], P>0.05}, and showed a declining trend in group B4 (60 keV) {4 [4, 5] *vs.* 5 [4, 5], P>0.05}.

Conclusions: It is feasible to perform run-off CTA using low-dose CM with VMI on SDCT. The VMIs at 40–50 keV were the optimal choice and did not compromise IQ.

Keywords: Spectral detector computed tomography; virtual monoenergetic images (VMIs); lower extremity; contrast media (CM)

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Introduction

As a convenient, safe, accurate, and economical tool, computed tomography angiography (CTA) is broadly utilized in clinical practice, and has become a predominant substitute for digital subtraction angiography in preoperative diagnosis and postoperative assessment of peripheral arterial disease (1-3). Iodinated contrast media (CM) can enhance the visualization of vessels and improve the contrast of the region of interest against adjacent tissue, which is especially necessary for CTA (4). More CM is needed in the lower extremities compared with other areas, but adverse effects may increase with the CM dose used (5-9). Therefore, it is of clinical interest to reduce the amount of contrast used.

With the development of dual-energy technology, virtual monoenergetic images (VMIs) of dual-energy CT (DECT) have been found to increase intravascular contrast at low energy levels, and are useful in the reduction of CM (10-13). Almutairi *et al.* reported the feasibility of using low-dose CM with VMIs on rapid kVp switching CT (KVSCT) in run-off CTA (14). However, the low energy level VMI technique is limited by the increasing noise produced as energy level decreases (15).

Dual-layer spectral detector CT (SDCT), which is different from other DECT techniques [such as KVSCT, dual-source CT (DSCT)] that achieve energy separation at the source level, can simultaneously acquire dual-energy projection information at the same spatial and temporal resolution at the detector level (10,11,16,17). In comparison with other DECT types, SDCT is superior in reducing noise by near-perfect alignment projection data from the bottom and upper layers, and utilizing an anticorrelated noise reduction algorithm while maintaining low noise in all energy level VMIs (10,17-19). This is beneficial for reducing CM at low-energy level VMIs without impairing image quality (IQ) (19). Some studies have examined reducing CM in coronary CTA by using VMI on SDCT; however, the clinical application of VMIs on SDCT with low-dose CM in run-off CTA has not been reported. Therefore, the aim of the present study was to assess the feasibility of low-dose CM with VMIs in run-off CTA on SDCT, with the hypothesis that in run-off CTA, VMIs with low-dose CM are not inferior to conventional images with full-dose CM in terms of IQ. We also explored the optimal VMI use among patients with lower extremity arteriosclerosis obliterans.

Methods

Population

This prospective randomized study was approved by our institutional review board, and informed consent was obtained from all the patients.

Patients from the Division of Interventional Radiology of Shengjing Hospital of China Medical University who were clinically suspected of lower extremity arteriosclerosis obliterans and presented for further treatment were enrolled in the study (48 patients, from May 2019 to March 2020). The exclusion criteria were as follows: contraindication to iodinated CM, renal insufficiency (n=4), body mass index (BMI) >30 kg/m^2 (n=1), a history of stenting or bypass surgery in the lower extremity arteries (n=3). Forty patients were finally included and randomly distributed into a control group (group A, n=20, using routine volume CM) and an experimental group (group B, n=20, using half-volume CM) by a random-number table.

CT scanning protocol

All patients underwent craniocaudal scanning, including of the distal abdominal aorta and toes by SDCT (IQon, Philips Healthcare, the Netherlands). In group A, the volume of CM (Shuangbei Iohexol 350; Beilu Pharmaceutical, Beijing, China) was 90 mL and was injected intravenously at a flow rate of 4 mL/s, followed by a saline injection of 30 mL at 4 mL/s. In group B, the volume of CM was 45 mL and was injected at a half flow rate, and was followed by an injection of half-volume saline. Each scan used the bolus-tracking technique and was delayed 16 s after the distal abdominal aorta signal achieved attenuations of 150 HU (group A) and 100 HU (group B). The other scan parameters were the same in both groups: slice collimation, 64×0.625 mm; rotation time, 0.5 s; pitch, 0.96; matrix, 512×512; dose modulation type, DoseRight 3D-DOM (Philips Healthcare, the Netherlands); and tube voltage, 120 kVp.

Image reconstruction

Slice thickness and increment in the process of image reconstruction in both groups was set at 1 mm. In groups A and B, 120 kVp polychromatic conventional images were routinely generated via a hybrid iterative reconstruction algorithm (iDose 4, level 3), defined as A1 and B1, respectively. Additionally, in group B, VMIs (range, 40–120 keV) at 10 keV intervals were reconstructed via a spectral reconstruction algorithm (Spectral B, level 3), defined as B2–B10. Images >120 keV energy levels were not evaluated because of poor vascular contrast (1). All images were then transferred to a workstation (IntelliSpace Portal 9.0; Philips Healthcare, The Netherlands). Window settings (width, 350; level, 45) were defaults and could be modified as desired.

Objective IQ evaluation

A professional radiologist with 4 years of CTA experience completed all measurements. The mean vascular attenuation (HU) of bilateral common iliac arteries, common femoral arteries, middle superficial femoral arteries, middle popliteal arteries, tibiofibular stem arteries, and adjacent muscle at the same slice, were measured in axial images three times. The standard deviation (SD) of vascular attenuation was deemed as image noise. The signal-to-noise ratio (SNR) and contrast-to-noise ratio (CNR) were acquired based on the following formulas: SNR = HUartery/SDartery and CNR = (HUartery − HUmuscle)/SDartery (20). Target areas were made as large as possible within the luminal diameter, and edges of vessels, atherosclerotic plaques, and calcifications were avoided. In addition, target arteries that were occlusive or had stenoses with residual diameter of <2 mm were excluded. A total of 382 eligible vascular locations were included in the present study.

Subjective IQ evaluation

The subjective assessment was independently completed by two radiologists with 9 and 12 years of CTA experience. Subjective IQ was scored on a 5-point scale, with 1 being poor and 5 being perfect, using the following parameters: noise, artifacts, contrast, and sharpness. The detailed scoring criteria are described in our previous study (20), and included transverse images, maximum intensity projections, and curved planar reformation images of A1, B1, and B2–B10. In cases where there was disagreement between the two radiologists, the score was determined by consensus.

Radiation dose analysis

The volume CT dose index (CTDIvol) and the dose length product (DLP) of each patient were acquired based on the dose report for the radiation dose analysis. The effective dose (ED) was calculated based on a previously published study (21).

Statistical analysis

All data analyses were completed with SPSS version 23.0 (IBM, Armonk, NY, USA) and GraphPad Prism version 8.0 (GraphPad Software, Inc., San Diego, CA, USA). Quantitative data are expressed as mean ± SD, and qualitative data are expressed with frequencies. Variables of age, sex, body weight, height, BMI, and CTDIvol, DLP, and ED of groups A and B were compared by paired samples *t*-test or χ^2-test. Analysis of variance was applied in the analysis of the vascular attenuation, noise, SNR, and CNR of A1 and B1–B10. Furthermore, the Fisher's least significant difference test or Dunnett's T3 test was used in post-hoc tests between pairwise comparisons. IQ scores are expressed as medians with interquartile ranges, and the Kruskal-Wallis test was used in the analysis of IQ scores. A P value <0.05 was deemed statistically significant. Cohen's kappa test was used to assess interobserver agreement, as proposed in previously published studies (20,22).

Results

Patient demographics and radiation dose

Forty patients were included in the present study, with 20 each in group A (group A: 14 males and 6 females; group B: 15 males and 5 females). The average age was 67.40±6.83 and 69.25±9.97, ranging from 56 to 81 years and 45 to 82 years in groups A and B, respectively. Differences in age, sex, height, weight, and BMI between groups A and B were not significant. No statistically significant differences in DLP, CTDIvol, or ED were found between the two groups (*Table 1*).

Objective IQ

The mean attenuation was higher in group B2 and was lower in group B3 compared with group A1, but neither difference reached statistical significance. Furthermore, the mean attenuation in group B1 and groups B4–B10 was lower than that in group A1 (P<0.05). The mean noise was similar in group B2 (P>0.05) to that in group A1, but lower in group B1 and groups B3–B10 (P<0.05). The mean SNR and CNR in group B2, as well as the mean SNR in group

Table 1 Patient demographics and radiation doses

Item	Group A	Group B	P value
Age (year)	67.40±6.83	69.25±9.97	0.500
Sex (male/ female)	14/6	15/5	0.613
Height (cm)	171.55±8.01	170.00±8.56	0.595
Weight (kg)	70.7±6.24	69.15±7.96	0.539
BMI (kg/m^2)	24.01±1.13	23.86±1.30	0.659
DLP (mGy·cm)	1,823.45±512.68	2,014.40±453.25	0.229
CTDIvol (mGy)	14.92±3.40	16.26±2.85	0.208
ED (mSv)	10.82±3.02	11.88±2.67	0.229

Data are presented as means ± standard deviations or frequencies. BMI, body mass index; CTDIvol, volume computed tomography dose index; DLP, dose length product; ED, effective dose.

B3, were higher than those in group A1 (P<0.05), and the mean CNR in group B3 was similar to that in group A1 (P>0.05). The mean SNR and CNR in group B1 and groups B4–B10 were similar or significantly lower than those in group A1 (*Figure 1* and *Table 2*). Example axial images of group A1 and groups B1–B10 are shown in *Figure 2*.

Subjective IQ

Subjective IQ scores in groups B2 and B3 were similar and showed a declining trend in group B4 compared with those of group A1 (*Table 3*). The differences between B2 versus A1, B3 versus A1, and B4 versus A1 were not significant. Scores of group B1 and groups B5–B10 were significantly inferior to those of group A1 (P<0.05). Example images are

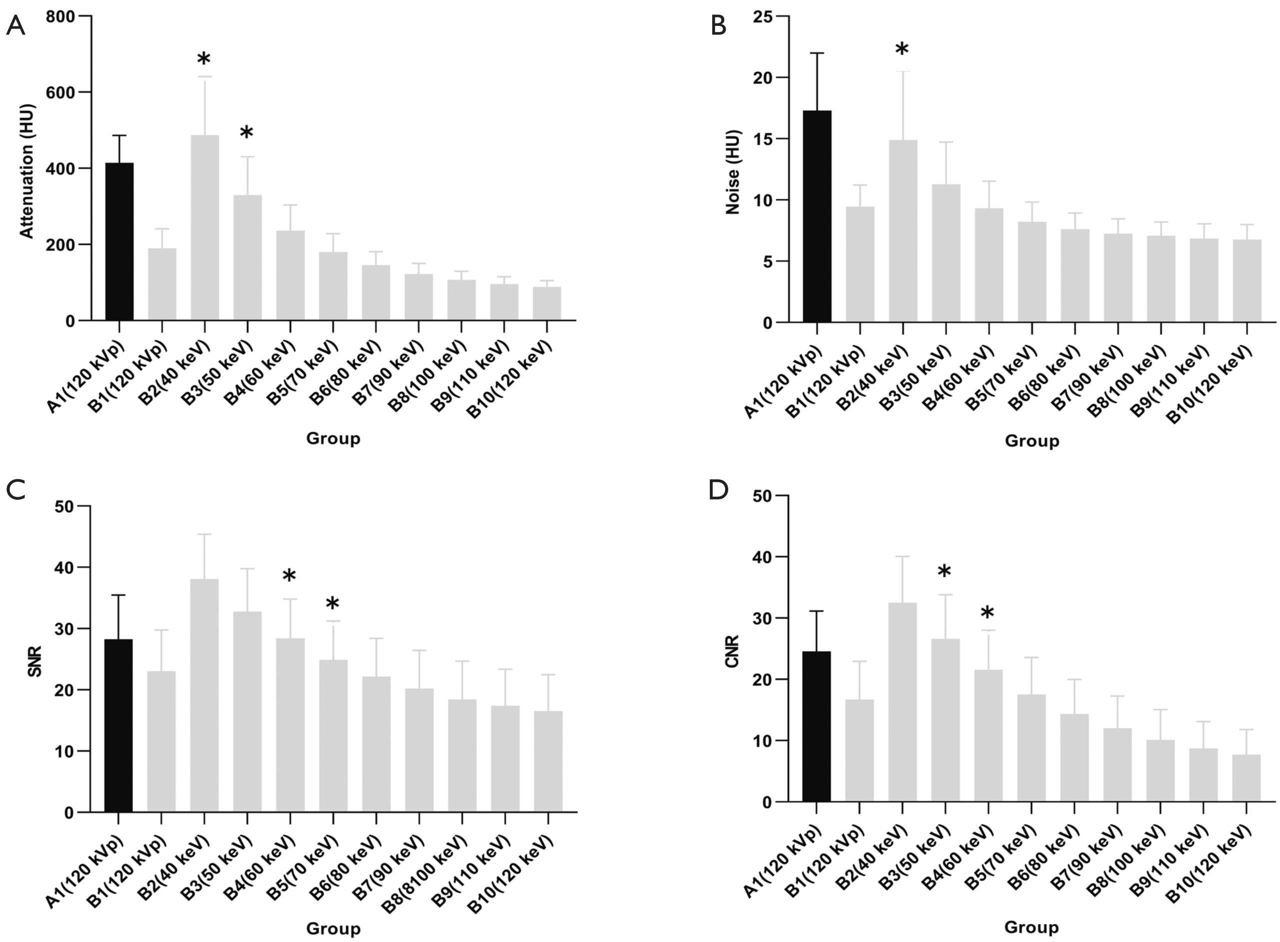

Figure 1 Graphs showing the results of mean vascular attenuation (A), noise (B), signal-to-noise ratio (SNR) (C), and contrast-to-noise ratio (CNR) (D). A1, 120 kVp polychromatic conventional images using routine volume contrast media; B1 and B2–B10, 120 kVp polychromatic conventional images and virtual monoenergetic images (40–120 keV), respectively, using half-volume contrast media. The difference was significant except between groups A1 and B1–B10 (*).

Table 2 Results of objective image quality analysis

Item	A1 (120 kVp)	B1 (120 kVp)	B2 (40 keV)	B3 (50 keV)	B4 (60 keV)	B5 (70 keV)	B6 (80 keV)	B7 (90 keV)	B8 (100 keV)	B9 (110 keV)	B10 (120 keV)
CT (HU)	414.35±71.66	189.39±51.93***	487.07±154.21	329.90±100.25	236.13±67.21***	180.26±47.76***	145.40±35.90***	122.62±28.01***	106.97±22.87***	96.03±19.00***	88.24±16.53***
SD (HU)	17.29±4.70	9.45±1.77***	14.81±5.67	11.26±3.42***	9.31±2.20***	8.22±1.59***	7.61±1.31***	7.23±1.21***	7.07±1.13***	6.84±1.20***	6.75±1.23***
SNR	28.25±7.20	23.06±6.74***	38.21±7.52**	32.85±7.10**	28.41±6.39	24.89±6.34	22.13±6.27***	20.17±6.25***	18.42±6.27***	17.41±5.94***	16.53±5.93***
CNR	24.54±6.60	16.69±6.26***	32.70±7.79**	26.66±7.32	21.56±6.46	17.51±6.04***	14.36±5.63***	12.02±5.25***	10.09±4.96***	8.73±4.37***	7.63±4.12***

Data are presented as means ± standard deviations. A1, 120 kVp polychromatic conventional images using routine volume contrast media; B1 and B2–B10, 120 kVp polychromatic conventional images and virtual monoenergetic images (40–120 keV), respectively, using half-volume contrast media. ** and *** indicate that the values of groups B1–B10 were significantly increased and decreased, respectively, compared with those in group A1. CNR, contrast-to-noise ratio; SNR, signal-to-noise ratio.

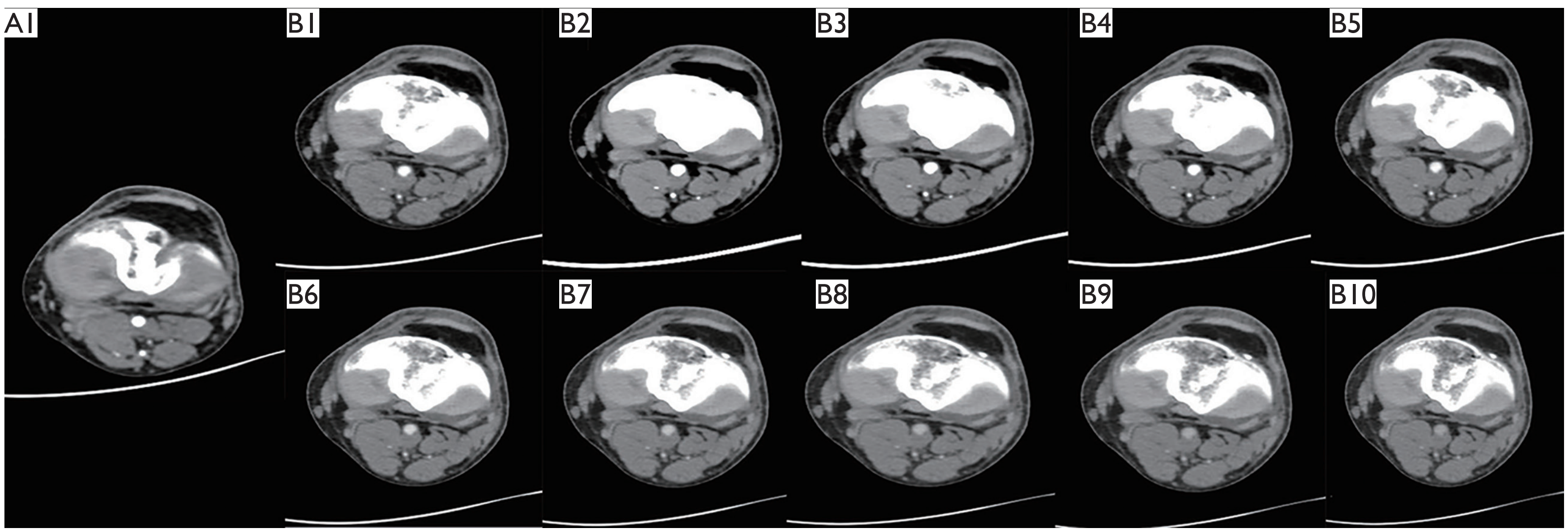

Figure 2 Transverse image example of left middle popliteal arteries for objective image quality analysis. (A1) 120 kVp polychromatic conventional images of a 65-year-old man using routine volume contrast media; (B1 and B2–B10) 120 kVp polychromatic conventional images and virtual monoenergetic images (40–120 keV), respectively, of a 71-year-old man using half-volume contrast media.

Table 3 Results of subjective IQ analysis

Image series	IQ	P value	κ value
A1 (120 kVp)	5 [4, 5]		0.900
B1 (120 kVp)	4 [3, 4]	0.009	0.875
B2 (40 keV)	5 [4.25, 5]	0.545	0.688
B3 (50 keV)	5 [5, 5]	0.449	0.692
B4 (60 keV)	4 [4, 5]	0.359	1
B5 (70 keV)	4 [3, 4]	0.003	0.894
B6 (80 keV)	3 [3, 4]	<0.001	0.912
B7 (90 keV)	3 [3, 3]	<0.001	0.823
B8 (100 keV)	3 [2, 3]	<0.001	0.732
B9 (110 keV)	2 [1.25, 3]	<0.001	0.922
B10 (120 keV)	1 [1, 2]	<0.001	0.798

Subjective image quality (IQ) scores are expressed as medians with interquartile ranges. P values were the results of comparisons among groups A1 and B1–B10. A1, 120 kVp polychromatic conventional images using routine volume contrast media; B1 and B2–B10, 120 kVp polychromatic conventional images and virtual monoenergetic images (40–120 keV), respectively, using half-volume contrast media.

presented in *Figure 3*. Interobserver agreement was good to excellent (range, κ≥0.688; P<0.05).

Discussion

To the best of our knowledge, the present study is the first report describing the application of VMIs derived from SDCT in run-off CTA while using a lower dose of CM for patients with lower extremity arteriosclerosis obliterans. We demonstrated the feasibility of using low-dose CM with VMIs, while providing satisfactory IQ for diagnosis on SDCT. The VMI at 40–50 keV in group B, which used low-dose CM, could provide sufficient vascular contrast, similar or lower noise, comparable or higher SNR and CNR; and comparable subjective IQ scores as those in group A, which used routine volume CM.

VMI can improve vascular contrast on the basis of higher iodine attenuation at lower energy, because of the increase in photoelectric attenuation when energies approach the K-edge of iodine (33.2 keV). This is indispensable for reducing CM, while the enhancement degree of blood vessels is essential for ensuring IQ. Fei *et al.* found that the optimal vessel attenuation was about 350 HU (23), whereas 200 HU was clinically acceptable, but might impact the diagnostic accuracy for evaluating coronary arteries. The findings of the present study indicated that the objective indices and subjective IQ scores at 40–50 keV in group B were equal or higher compared with those in group A. Although the SNR and CNR at 60 keV in group B were similar to those in group A1, the subjective score showed a declining trend compared with group A1, and the decreased vascular contrast was a possible explanation for this. Furthermore, IQ of ≥70 keV VMI worsened as vascular enhancement decreased.

Using low-tube voltage with the reduction of CM may result in increasing noise, which impairs IQ. Qi *et al.* found that the noise in a 70 kVp group using 80 mL of CM was significantly higher compared with that in a 120 kVp group using 120 mL of CM in run-off CTA on DSCT (3). VMIs were generated by using an anticorrelated noise reduction algorithm in the reconstruction process, which can minimize the noise on SDCT (18). Previous studies showed that VMIs derived from SDCT were superior in reducing noise compared to those from DSCT and KVSCT, and had low noise among all VMI ranges on SDCT (40–200 keV) (18,24). Our findings indicated a uniformly low image noise level among all studied VMIs, which is in agreement with other studies (18,24). This can potentially improve contrast signal, SNR, CNR, and lesion conspicuity (18).

Huang *et al.* reported that it was feasible to perform coronary CTA using half-dose CM with VMI on SDCT, and demonstrated that the objective indices and subjective IQ of VMI at 50 keV with half-dose CM were equal or superior to those in the control group subjected to full-dose CM (19). Oda *et al.* also demonstrated the feasibility of using VMI at 50 keV, with a 50% reduction of CM in coronary CTA on SDCT without impairing IQ in patients with renal insufficiency (25). The present study substantiates the results of previous studies by showing that it is viable to use low-dose CM without compromising IQ in run-off CTA on SDCT. However, Huang *et al.* found the optimal VMIs were obtained at 50 keV in coronary CTA (19), whereas the optimal VMIs were obtained at 40–50 keV in the present study in run-off CTA. This difference might be due to the optimal VMI varying across the different locations.

The present study has some limitations. First, the sample size was relatively small and confined to patients selected from a single center. Further studies should include a larger sample size. Second, we did not compare serum creatinine levels before and after scanning, nor did we assess the effect on the risk of contrast-induced nephropathy. Third, we performed an IQ assessment, and a comparison of diagnostic accuracy to the accepted gold-standard DSA can be undertaken in future. Fourth, the energy interval

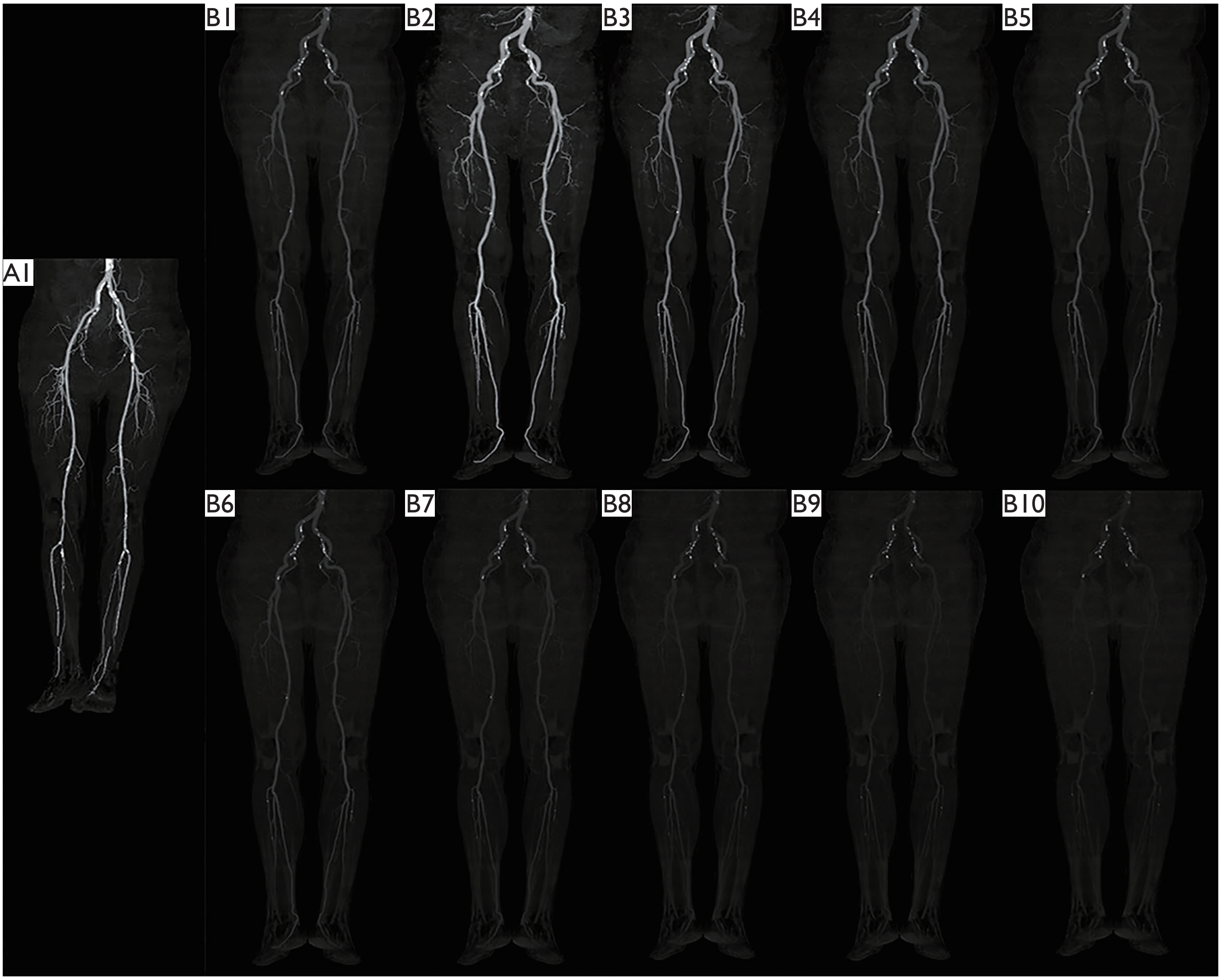

Figure 3 Maximum intensity projection images for subjective image quality (IQ) analysis. (A1) 120 kVp polychromatic conventional images of a 65-year-old man using routine volume contrast media; (B1 and B2–B10) 120 kVp polychromatic conventional images and virtual monoenergetic images (40–120 keV), respectively, of a 71-year-old man using half-volume contrast media.

(10 keV) was relatively large, and smaller intervals should be used in further work. Fifth, the volume of CM used was based on routine practice instead of the body weight of patients, and the strategy to lower CM dose might not be the accepted standard of care.

Conclusions

Low-dose CM with VMI in run-off CTA on SDCT can be used for patients with lower extremity arteriosclerosis obliterans, and VMIs at 40–50 keV are considered to be the optimal choice in clinical application as this does not reduce IQ.

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Footnote

Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form (available at http://dx.doi.org/10.21037/qims-20-925). The authors have no conflicts of interest to declare.

Ethical Statement: The present study was approved by our institutional review board, and informed consent was obtained from all patients.

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