ORIGINAL ARTICLE

Feasibility of Reduced Radiation Dose and Iodine Load in Lower Extremity Computed Tomography Angiography

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ABSTRACT

Objective: *To evaluate the feasibility of reduced radiation dose and low-concentration contrast medium in lower extremity computed tomography angiography (CTA) compared with conventional automatic exposure control CTA.*

Methods: *A total of 64 subjects underwent dual-source CTA operating in dual-source, high-pitch mode, using both high-concentration contrast medium (group A, n = 31; iomeprol 400 mg I/mL) and low-concentration contrast medium (group B, n = 33; iodixanol 270 mg I/mL). Group A was scanned using a reference tube voltage of 120 kVp and reference 100 mAs under automatic exposure control with iterative reconstruction. Group B was scanned using low tube voltage (80 kVp or 100 kVp if body mass index ≥25 kg/m²) and fixed 120 mAs, along with iterative reconstruction. Images of the two groups were compared regarding attenuation, image noise, signal-to-noise ratio, contrast-to-noise ratio, iodine load, radiation dose, and visual quality assessment (general, enhancement, sharpness, and noise) in various locations of CTA.*

Results: *The averages of mean attenuation (765.29 ± 146.3 vs. 581.11 ± 163.99 HU), signal-to-noise ratio (42.93 ± 10.85 vs. 30.97 ± 9.54), and contrast-to-noise ratio (39.89 ± 10.53 vs. 27.82 ± 9.12) were significantly higher in group A than in group B (all $p < 0.05$). Visual quality comparisons in each location were not significantly different.*

Conclusion: *In lower extremity CTA, reduced radiation dose and iodine load in CTA scans with low-concentration contrast medium and low tube voltage may not yet be a feasible replacement for conventional automatic exposure control CTA.*

Key Words: *Angiography; Computed tomography angiography; Radiation dosage; Signal-to-noise ratio*

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Ethics Approval: The study protocol was approved and the requirement for patient informed consent was waived by the institutional review board (Ref CNUH 2017-06-075).

中文摘要

下肢電腦斷層掃描血管造影中降低輻射劑量和碘負荷的可行性

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目的：評價與常規自動曝光控制電腦斷層掃描血管造影（CTA）相比，下肢CTA降低輻射劑量和低濃度造影劑的可行性。

方法：共64名受試者在雙源大螺距掃描模式下進行CTA，同時使用高濃度造影劑（A組，31例，碘美普爾400 mg I/mL）和低濃度造影劑（B組，33例，碘克沙醇270 mg I/mL）。掃描A組時使用標準管電壓120 kVp和標準管電流100 mAs，並以自動曝光控制結合迭代重建。掃描B組時使用低管電壓（80 kVp，或體重指數≥25 kg/m^{2}時使用100 kVp）和固定管電流120 mAs，同時進行迭代重建。在CTA不同位置比較兩組圖像的衰減值、噪聲、信噪比、對比噪聲比、碘負荷，輻射劑量和視覺質量評估（整體、增強度、銳利度和噪聲）。

結果：A組的平均衰減值（765.29比581.11 HU）、信噪比（42.93比30.97）和對比噪聲比（39.89比27.82）均顯著高於B組（$p < 0.05$）。每個位置的視覺質量比較沒有顯著差異。

結論：在下肢CTA中使用低濃度造影劑和低管電壓的CTA掃描雖可降低輻射劑量和碘負荷，但仍不能成為傳統自動曝光控制CTA的可行替代方案。

INTRODUCTION

Computed tomography angiography (CTA) is a well-known minimally invasive diagnostic method for assessing and monitoring suspected peripheral artery disease. Generally, a high-concentration iodinated contrast medium (CM) is used to increase vascular attenuation in lower extremity CTA. The results in an increase of total iodine load, which is an important risk factor in contrast-induced nephropathy.[1,2]

Reduced tube voltage could bring the mean photon energy in the X-ray spectrum closer to the K-edge of iodine (33.2 keV), leading to a higher mean CT attenuation value of iodine. On this basis, recent studies have demonstrated the feasibility of CTA with low tube voltage; even with a lower iodine concentration of CM, CTA provides similar enhancement and image quality in several vascular territories with the benefit of a lower radiation dose than with conventional CTA with high tube voltage and higher iodine concentration of CM.[3-11] However, few reports have addressed the feasibility of using lower iodine concentration CM with low-tube-voltage lower extremity CTA in comparison with conventional CTA using higher iodine concentration CM with automatic exposure control.[12,13]

The purpose of the present study was to evaluate the feasibility of low-concentration CM for vascular enhancement, image quality, and radiation dose on lower extremity CTA using a combined low tube current and iterative reconstruction (IR) technique.

METHODS

Patient Population

Between January 2015 and January 2016, 75 patients underwent lower extremity dual-source CTA to confirm or rule out suspected peripheral arterial occlusive disorder. Dual-source CT scans were performed using iomeprol 400 (Imeron 400 mg I/mL; Bracco, Milan, Italy) for patients from January to August 2015 (group A). From September 2015 to January 2016, iodixanol 270 (Visipaque 270 mg I/mL; GE Healthcare, Little Chalfont, United Kingdom) was used (group B). Group A patients underwent conventional CTA using automatic exposure control. Group B patients underwent low-dose CTA protocol and were further divided into two subgroups with respect to body mass index (<25 kg/m^2 or ≥25 kg/m^2) in which the tube voltage was individualised. Exclusion criteria included renal insufficiency (serum creatinine >132.6 μmol/L), previous allergic reaction to iodinated contrast material, motion artefacts resulting in poor CTA image quality, history of surgical arterial operation in lower extremity including stent insertion, unilateral or bilateral arterial total occlusion, preoperative arterial evaluation in fracture patients in traffic accident, underlying diabetes mellitus, and severe atherosclerosis associated dense calcic plaque deposition cases. A total of 11 cases were excluded. The presentations for lower extremity CTA in the 64 enrolled patients included unremarkable findings (n = 42), mild atherosclerosis (n = 21), and Baker's cyst (n = 1).

Before scanning, the age, sex, height, body weight, and echocardiographic ejection fraction were recorded for each patient from medical records. Our institutional review board approved the study and waived the requirement for informed consent as this investigation was retrospective.

Computed Tomography Scan Protocol

All procedures were performed using a second-generation dual-source CT scanner (SOMATOM Definition Flash; Siemens Healthcare, Forchheim, Germany) operating in dual-source mode with pitch of 0.5, collimation of 128 × 0.6 mm using z-flying focal spot, and rotation time of 0.5 s. In group A, reference tube voltage of 120 kVp and reference tube current of 100 mAs automatic exposure control (CARE kV, CARE Dose 4D, Siemens Healthcare) was used. In group B, tube voltage of 80 kVp (or 100 kVp if body mass index ≥25 kg/m^2) and fixed tube current of 120 mAs was used. Scans in both groups were performed in a craniocaudal direction from the infrarenal abdominal aorta to the feet. Contrast administration was controlled with bolus tracking. The automatic trigger scan started with a 12-s delay in both groups after reaching the attenuation threshold of 100 Hounsfield units (HU) at the abdominal aortic bifurcation. The total injected amount of CM was decided according to the patient's body weight (1.6 mL/kg) and each patient received CM at a flow rate of 4 mL/s followed by a 50 mL saline chaser through an 18-gauge needle in the antecubital vein using a Medrad Stellant D dual-syringe power injector (Bayer, Indianola [PA], United States). The amount of total iodine used in each patient was calculated as: [iodine concentration (mg I/mL) × 1.6 mL/kg × body weight (kg)] / 1000 (mg/g).

Computed Tomography Image Reconstruction

Original scan data were transmitted to the Siemens workstation (SyngoMMWP VE40A, Siemens Medical Solutions, Forchheim, Germany). Transverse images were reconstructed at 0.75-mm slice thickness with a 0.5-mm increment using a sonogram-affirmed IR (SAFIRE, Siemens Healthcare, Forchheim, Germany) algorithm with a medium-smooth convolution kernel (I30f), medium strength of level 2, image matrix of 512 × 512 pixels, and field of view of 250 to 450 mm. Additional multiplanar reconstruction with slice thickness of 5.0 mm and increment of 5.0 mm using the same IR techniques was performed and transferred to a regular picture archiving and communication system workstation (Maroview V5.4.10.42, INFINITT Healthcare, Seoul, Republic of Korea).

Image Analysis

For quantitative evaluation, contrast enhancement, attenuation, and noise values in various locations of the infrarenal abdominal aorta, both sides of the common iliac arteries, external iliac arteries, superficial femoral arteries, and popliteal arteries were measured in consensus by two radiologists (JWP and SSK) with 10 years and 2 years of experience, respectively, in interpreting CTA images. To measure the values in each artery on axial images, a circular region-of-interest cursor was drawn as large as possible within the vessels with care taken to avoid the calcific or soft plaque and stenosis (Figure 1). The attenuation of the psoas and thigh muscles and the noise within subcutaneous fat (standard deviation of the CT attenuation) were also measured at each location. Attenuation and noise values expressed in HU within each circular region of interest were measured twice and the average value was calculated for each anatomic site. Based on these measurements, the signal-to-noise ratio (SNR) was calculated by the attenuation value / noise value at each anatomic site. Contrast-to-noise ratio (CNR) was calculated as follows: CNR = (mean attenuation of each site of aorta – attenuation of muscle) / noise.[12]

Qualitative analyses were independently assigned in a blind fashion by the aforementioned two radiologists and all images in the two groups were reviewed in random order. All images were evaluated primarily at a window level of 60 HU and a width of 1000 HU. Subjective image quality was graded according to the quality of the general image impression, enhancement, sharpness, and image noise on CTA using a 5-point Likert-type scale (5 = excellent; 4 = good; 3 = moderate; 2 = fair; 1 = poor). Grades of 2, 3, 4 and 5 were assumed to be diagnosable.

Measurement of Radiation Dose

The CT dose index volume and dose-length product were recorded during CT scans. The estimated effective dose was measured only at the abdomen and pelvis regions, since the exposure of the lower extremities contributes only minimally to the overall effective dose and the conversion factors for legs are unavailable. The effective dose was calculated at the abdomen and the pelvis as:

Effective dose = dose-length product × k × tissue weighting factor,

where k is the conversion coefficient (k = 0.015 at the abdomen; k = 0.019 at the pelvis) and the tissue weighting factor is 0.05.[14]

Statistical Analyses

Statistical analyses were performed using SPSS (Windows version 12.1.1; SPSS Inc., Chicago [IL], Unite States). Quantitative data were expressed as mean ± standard deviation and analysed using an independent *t* test in normally distributed data and a Mann-Whitney *U* test in non-normally distributed data. The independent *t* test was performed to analyse the difference between two groups regarding attenuation value, image noise, SNR, CNR, and radiation dose. Repeated-measures analysis of variance was performed to evaluate the difference regarding the homogeneity of contrast enhancement between the two groups. The Chi square test was used to determine the difference in proportion to the subjective scoring rate for image quality between the two groups. Cohen's kappa statistics were used to assess inter-observer agreements for the subjective assessment of image quality. The kappa value was interpreted using the guidelines of Landis and Koch (>0.81, almost perfect agreement; 0.61-0.80, substantial agreement; 0.41-0.60, moderate agreement; 0.20-0.40, fair agreement; <0.20, poor agreement).[15] For all data analyses, a p value <0.05 was considered statistically significant.

RESULTS

Patient demographics are shown in Table 1. CT scans

Table 1. Demographic data of 64 patients who underwent dual-source computed tomography angiography using high-concentration contrast medium (group A) and low-concentration contrast medium (group B).*

	Group A (iomeprol 400)	Group B (iodixanol 270)	p Value
No. of patients (male)	31 (20)	33 (19)	0.569
Age (years)	63.5 ± 12.5	61.2 ± 17.4	0.543
Height (cm)	164.2 ± 9.4	163.6 ± 7.7	0.781
Body weight (kg)	64.6 ± 10.9	59.8 ± 10.4	0.075
Body mass index (kg/m^2)	23.9 ± 2.7	22.3 ± 3.0	0.040
Ejection fraction (%)	59.0 ± 2.7	60.7 ± 6.0	0.519

* Data are shown as mean ± standard deviation, unless otherwise specified.

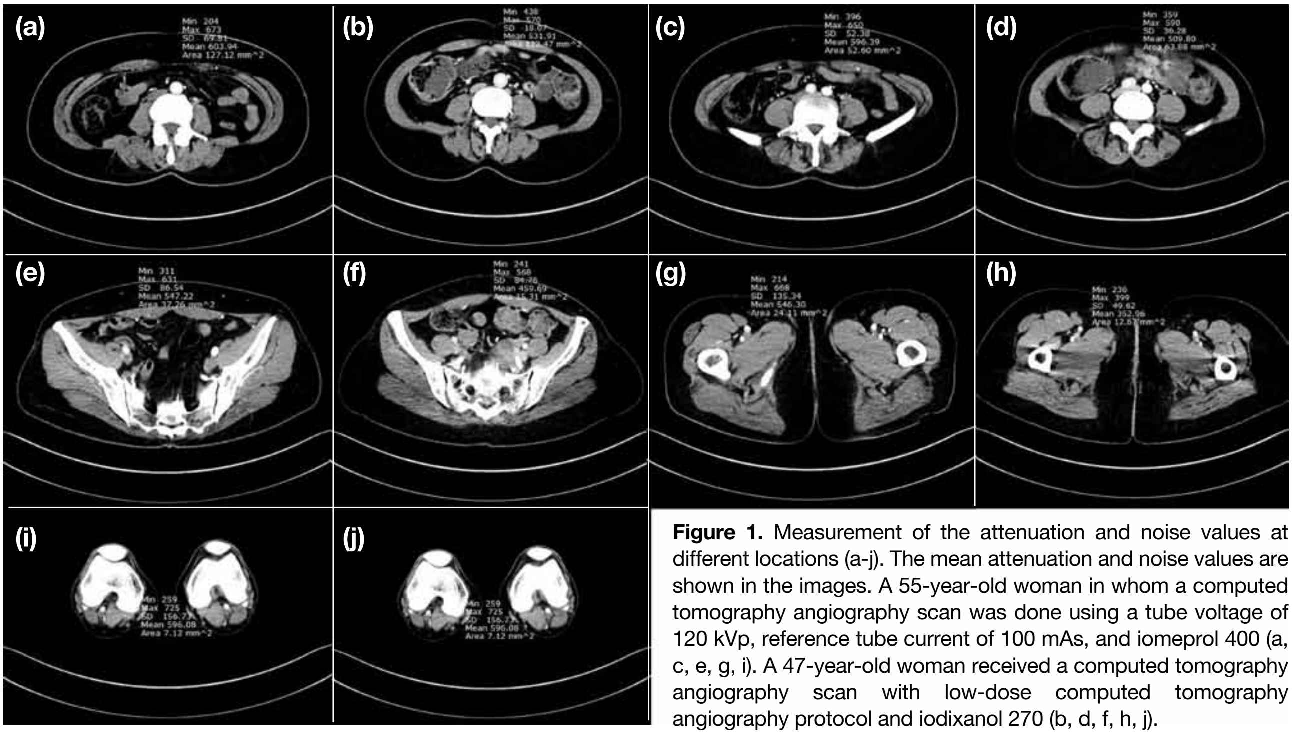

Figure 1. Measurement of the attenuation and noise values at different locations (a-j). The mean attenuation and noise values are shown in the images. A 55-year-old woman in whom a computed tomography angiography scan was done using a tube voltage of 120 kVp, reference tube current of 100 mAs, and iomeprol 400 (a, c, e, g, i). A 47-year-old woman received a computed tomography angiography scan with low-dose computed tomography angiography protocol and iodixanol 270 (b, d, f, h, j).

Table 2. Attenuation, image noise, signal-to-noise ratio and contrast-to-noise ratio in images of patients who underwent dual-source computed tomography angiography using high-concentration contrast medium (group A) and low-concentration contrast medium (group B).*

Locations	Group A (iomeprol 400)	Group B (iodixanol 270)	p Value
Infrarenal abdominal aorta			
Attenuation (HU)	731.19 ± 131.01	593.75 ± 141.14	0.000
Image noise (HU)	17.65 ± 13.55	16.87 ± 4.42	0.760
Signal-to-noise ratio	49.42 ± 18.22	37.81 ± 14.01	0.006
Contrast-to-noise ratio	45.48 ± 17.28	34.18 ± 13.39	0.005
Right common iliac artery			
Attenuation (HU)	752.29 ± 169.37	596.87 ± 154.56	0.000
Image noise (HU)	20.26 ± 13.41	19.29 ± 7.31	0.726
Signal-to-noise ratio	45.01 ± 18.49	33.76 ± 13.40	0.008
Contrast-to-noise ratio	41.53 ± 17.51	30.49 ± 12.98	0.006
Left common iliac artery			
Attenuation (HU)	751.19 ± 167.46	599.67 ± 154.36	0.000
Image noise (HU)	16.01 ± 8.09	17.54 ± 6.79	0.424
Signal-to-noise ratio	58.67 ± 35.59	37.72 ± 14.12	0.004
Contrast-to-noise ratio	54.19 ± 33.28	33.99 ± 13.32	0.003
Right external iliac artery			
Attenuation (HU)	756.03 ± 158.45	582.34 ± 163.08	0.000
Image noise (HU)	24.81 ± 13.81	25.61 ± 15.36	0.829
Signal-to-noise ratio	37.13 ± 17.49	28.78 ± 14.48	0.044
Contrast-to-noise ratio	34.08 ± 15.89	25.89 ± 13.42	0.031
Left external iliac artery			
Attenuation (HU)	751.61 ± 158.73	579.22 ± 164.67	0.000
Image noise (HU)	18.72 ± 8.93	24.04 ± 17.80	0.144
Signal-to-noise ratio	47.24 ± 19.84	33.92 ± 20.01	0.012
Contrast-to-noise ratio	46.37 ± 30.94	30.58 ± 19.22	0.020
Right superficial femoral artery			
Attenuation (HU)	784.77 ± 150.60	578.72 ± 186.57	0.000
Image noise (HU)	29.14 ± 21.94	32.72 ± 22.94	0.527
Signal-to-noise ratio	35.58 ± 17.19	24.26 ± 14.49	0.006
Contrast-to-noise ratio	32.86 ± 16.13	21.72 ± 13.35	0.004
Left superficial femoral artery			
Attenuation (HU)	775.16 ± 149.13	569.51 ± 181.73	0.000
Image noise (HU)	28.02 ± 22.07	37.11 ± 27.84	0.155
Signal-to-noise ratio	39.89 ± 22.37	24.86 ± 20.30	0.007
Contrast-to-noise ratio	36.69 ± 20.52	22.31 ± 18.81	0.005
Right popliteal artery			
Attenuation (HU)	793.36 ± 175.38	566.48 ± 211.43	0.000
Image noise (HU)	34.44 ± 25.68	30.26 ± 22.68	0.498
Signal-to-noise ratio	34.61 ± 21.98	27.50 ± 17.97	0.168
Contrast-to-noise ratio	31.95 ± 20.34	24.32 ± 16.11	0.107
Left popliteal artery			
Attenuation (HU)	785.23 ± 177.92	562.24 ± 201.07	0.000
Image noise (HU)	31.30 ± 24.39	33.31 ± 26.35	0.755
Signal-to-noise ratio	38.27 ± 28.61	30.00 ± 24.82	0.227
Contrast-to-noise ratio	35.30 ± 26.51	26.77 ± 22.76	0.178
Average			
Attenuation (HU)	765.29 ± 146.3	581.11 ± 163.99	0.000
Image noise (HU)	24.48 ± 9.01	26.30 ± 12.19	0.503
Signal-to-noise ratio	42.93 ± 10.85	30.97 ± 9.54	0.000
Contrast-to-noise ratio	39.89 ± 10.53	27.82 ± 9.12	0.000

* Data are shown as mean ± standard deviation, unless otherwise specified.

were successful and diagnostic image quality was attained in all 64 patients (39 males, 25 females; mean age, 62.35 ± 14.95 years). There was no significant difference regarding age, height, body weight, or ejection fraction between the two groups ($p > 0.05$). However, there was statistically significant difference in body mass index between the two groups (23.9 ± 2.7 vs. 22.3 ± 3.0; $p = 0.04$).

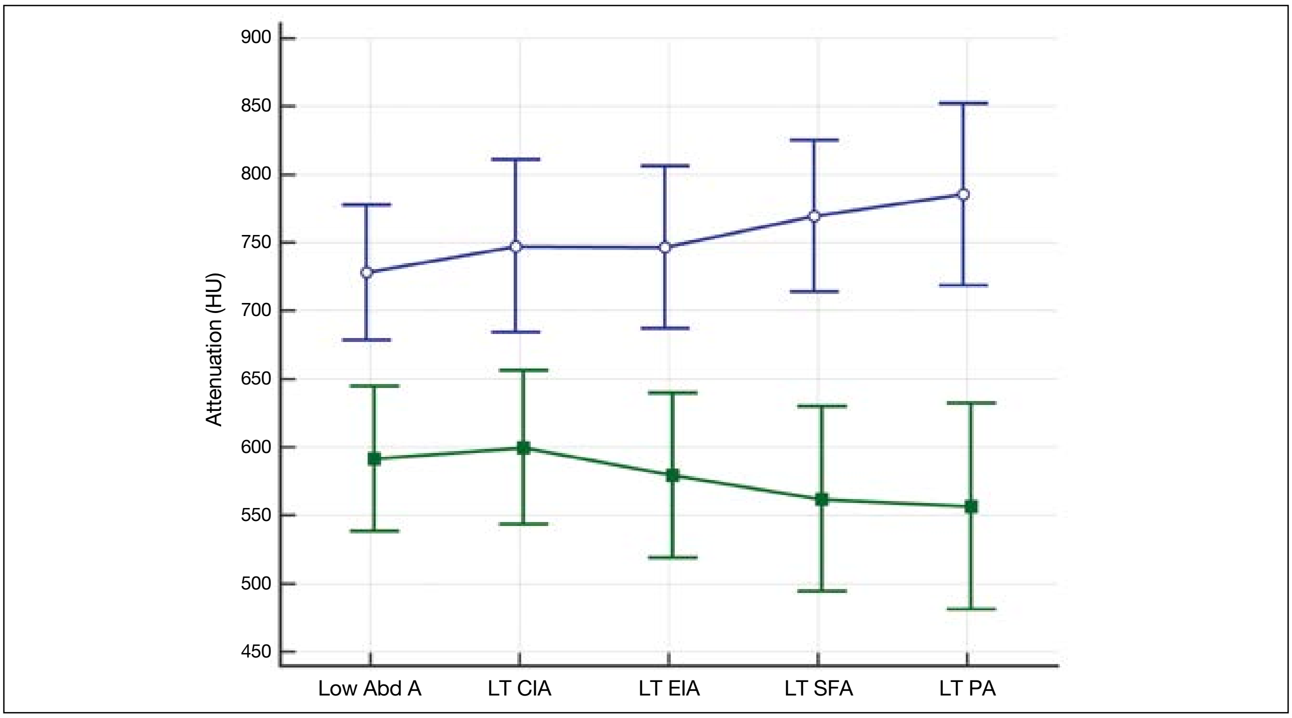

Figure 2. Attenuation at the different anatomic locations. The mean attenuation at each location in the aorta is greater in group A (open circles) than in group B (closed squares), indicating a superior homogeneous attenuation level of contrast enhancement and preserved distal attenuation from the lower abdominal aorta to the popliteal artery.
Abbreviations: HU = Hounsfield units; Low Abd A = lower abdominal aorta; LT CIA = left common iliac artery; LT EIA = left external iliac artery; LT PA = left popliteal artery; LT SFA = left superficial femoral artery.

Quantitative Evaluation of Contrast Enhancement

The averages over all locations of mean attenuation (765.29 ± 146.3 vs. 581.11 ± 163.99 HU), SNR (42.93 ± 10.85 vs. 30.97 ± 9.54), and CNR (39.89 ± 10.53 vs. 27.82 ± 9.12) in CTA were all significantly higher in group A than in group B (all $p < 0.001$) [Table 2]. For locations from the lower abdominal aorta to both superficial femoral arteries, attenuation, SNR, and CNR were higher in group A than in group B (all $p < 0.05$) [Figure 1, Table 2]. However, at these locations, no significant difference was found between the two groups regarding image noise. At the left and right popliteal artery level, attenuation was significantly higher in group A than in group B (both $p < 0.001$) [Table 2]. Regarding the comparison of homogeneity of contrast enhancement from the lower abdominal aorta to the left popliteal artery, group A showed a gradually increased and homogeneous attenuation level than in group B, significantly ($p < 0.001$, Figures 1 and 2).

Subjective Image Quality

Qualitative image analysis regarding the general image impression, enhancement, sharpness, and image noise revealed mean scores of image quality exceeding 4. Except for enhancement, the proportion of subjective scoring rate for image quality regarding general image

Table 3. Subjective scoring proportion of image quality of images of patients who underwent dual-source computed tomography angiography using high-concentration contrast medium (group A) and low-concentration contrast medium (group B).*

	Group A (iomeprol 400)	Group B (iodixanol 270)	p Value
General image impression			
Score 3	1 (3.2%)	3 (9.1%)	
Score 4	6 (19.3%)	8 (24.2%)	0.269
Score 5	24 (77.5%)	22 (66.7%)	
Enhancement			
Score 3	0	5 (15.1%)	
Score 4	7 (22.5%)	10 (30.3%)	0.016
Score 5	24 (77.5%)	18 (54.6%)	
Sharpness			
Score 3	0	1 (3%)	
Score 4	6 (19.3%)	10 (30.3%)	0.164
Score 5	25 (80.7%)	22 (66.7%)	
Image noise			
Score 3	3 (9.7%)	4 (12.1%)	
Score 4	11 (35.5%)	10 (30.3%)	0.883
Score 5	17 (54.8%)	19 (57.6%)	

* Data are shown as No (%). No patients had score 1 and 2.

Table 4. Iodine weight and radiation dose measurement of patients who underwent dual-source computed tomography angiography using high-concentration contrast medium (group A) and low-concentration contrast medium (group B).*

	Group A (iomeprol 400)	Group B (iodixanol 270)	p Value
Iodine weight (g)	31.04 ± 5.24	19.37 ± 3.39	0.000
Tube voltage (kVp)	120 ± 0.00	83.03 ± 7.28	0.024
Tube current (mAs)	189.06 ± 28.86	120 ± 0.00	0.000
CTDIvol (mGy)	3.73 ± 0.59	2.76 ± 0.94	0.000
DLP (mGycm)	450.71 ± 90.26	359.54 ± 135.22	0.003
Effective dose (mSv)	8.52 ± 1.75	6.83 ± 2.56	0.003

Abbreviations: CTDIvol = computed tomography dose index volume; DLP = dose-length product.

* Data are shown as mean ± standard deviation, unless otherwise specified.

impression, sharpness, and image noise were not significantly different between both groups (Table 3). The inter-observer agreements of linear weighted kappa values ranged from 0.65 to 0.83 (mean, 0.74). There was substantial agreement between the two readers in subjective ratings of image quality.

Iodine Weight and Radiation Dose Estimation

The administered iodine weight was significantly lower in group B (19.37 ± 3.39 g) than in group A (31.04 ± 5.24 g, $p < 0.001$; Table 4). A 37.6% reduction in iodine weight was noted in group B. Mean tube voltage, tube current, CT dose index volume, dose-length product, and estimated effective radiation dose were significantly lower in group B than in group A (all $p < 0.05$; Table 4). In comparison to group A, the average reduction in the mean estimated effective dose in group B was 19.8%.

DISCUSSION

Our results showed that the averages of mean attenuation, SNR, and CNR of conventional CTA with high-concentration CM using automatic exposure control with IR were significantly higher than those of CTA scanned with low-concentration CM and low-tube-voltage CTA with IR. Also, a gradual distal increase and homogeneous enhancement from the lower abdominal aorta to the popliteal artery was significantly superior in patients scanned with conventional CTA protocol with high-concentration CM.

Theoretically, the X-ray absorption of iodine increases with reduced tube voltage as long as the mean photon energy of X-rays is close to the K-edge of iodine (33.2 keV). Thus, reducing the tube voltage to 80 kVp can lead to a higher mean attenuation value of iodine in contrast-enhanced CT.[3-5] In addition, reducing the tube voltage to 80 kVp can reduce radiation dose 2.8 times compared with 120 kVp.[8] So the 80-kVp tube voltage technique potentially allows a dose saving of CM and radiation, although reduced tube voltage will inevitably be accompanied by increased image noise resulting in lower SNR and CNR. However, the present results differed from previous studies in the literature.[6-11,16-19] A previous study on CT aortography, using a combined technique with low-concentration CM and low-tube-voltage CT with IR, reported that image quality, enhancement, reduction of radiation dose, and homogeneous vascular attenuation in a wide scan range were better than those obtained using high-concentration CM in conventional CT aortography protocol.[7] In contrast, in the present study on lower extremity CTA, averages of mean attenuation, SNR, CNR, homogeneous contrast enhancement, and preserved distal attenuation from the lower abdominal aorta to the popliteal artery were significantly higher for conventional CTA with high-concentration CM than for a combination of low-concentration CM and low-tube-voltage CT with IR. This discrepancy may be mainly attributed to the fact that lower extremity CTA is markedly dependent on haemodynamic variation according to the individual patient's cardiac function and coexisting peripheral vascular disorders including stenosis or aneurysm, and a relatively smaller arterial diameter compared with other sites of CTA. All these factors make it much more dependent on the scan protocol-related contrast enhancement magnitude, the scan timing, and the difficulty in synchronising the enhancement of the entire lower extremity arterial tree. Therefore, we speculate that with the same scan protocols in group A and group B, the effect of CM concentration may offset the effect of tube voltage.

In the present study, image noise value and visual quality in each location were not significantly different between two groups, in contrast with previous studies.[6-13,17-21] We speculate that, regarding the lower extremity CTA, image noise does not increase as much in low-tube-voltage CTA and is not as great an influence on SNR, CNR, and visual quality in low-tube-voltage CTA with IR. Furthermore, the relatively long distance from the heart to the lower extremities and smaller arteries reduce the dilution effect of osmolarity and increase the influence of higher iodine concentration.

In the present study, the estimated effective dose and iodine load were significantly lower in group B than in group A. The average reduction in the estimated effective dose and iodine load from group A to group B was 19.8% and 37.6%, respectively. However, despite the benefits of low radiation dose, reduced iodine and lowered risk of contrast-induced nephropathy with low-concentration CM and low-tube-voltage CTA with IR, the averages of mean attenuation, SNR, and CNR of conventional CTA with high-concentration CM using automatic exposure control with IR remain superior.

The present study had some limitations. First, this study was retrospective, so it may be hard to confirm the same scan timing or enhancement magnitude in bolus geometry or coexisting peripheral vascular disorders even in the same scan protocol. Second, we did not evaluate and compare the diagnostic performance between the groups, only image quality. Third, the drawing of the circular regions of interest at the different anatomic levels was not exactly equal for each anatomic level. They were adjusted to the maximal vessel lumen with an effort to avoid calcification, thrombus, and motion artefacts. Fourth, the attenuation measurements were made in consensus rather than independently. Fifth, the sample size was relatively small.

In conclusion, in lower extremity CTA, reduced radiation dose and iodine load in CTA scans with low-concentration CM and low tube voltage may not yet be feasible for replacing conventional CTA using automatic exposure control with IR.

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