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The Feasibility of Combined Coronary and Supra-aortic Arteries CT Angiography with a Single High-pitch Acquisition Protocol using Dual-source CT

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Abstract

Objectives: To compare the image quality and radiation dose of combined coronary and supra-aortic arteries CT angiography (CTA) with a one stop shop single high-pitch acquisition protocol to that of separately acquisition protocol.

Materials and methods: This study screened 211 consecutively symptomatic patients who were suspected coronary artery disease and/or cerebrovascular diseases and a total of 164 patients were included in this study. Each group of 82 patients were randomly assigned in a 1:1 fashion to one of high-pitch combined coronary and supra-aortic arteries CTA acquisition protocol (group A) or separately acquisition protocol using high-pitch mode coronary CTA and Dual-energy mode carotid-cerebrovascular CTA (group B). The objective image quality including the enhancement values, image noise, signal-to-noise ratio (SNR) and contrast-to-noise ratio (CNR) of coronary and supra-aortic arteries were measured and calculated. The subjective image quality was evaluated according to the image quality scores.

Results: The average enhancement and image noise of supra-aortic arteries in group A were significantly higher than that of group B. The SNR and CNR measurements in the intra-cranial and extra-cranial carotid arteries did not show a statistically significant difference (all P>0.05). No significant difference was found for the mean image quality score either in coronary arteries or in the intra-cranial and extra-cranial carotid arteries between the two groups with regard to each score rate. The effective radiation dose was 1.36 ± 0.37 mSv in group A and 2.39 ± 0.38 mSv in group B (P<0.01).

Conclusion: The results of our study indicate that the combined coronary and supra-aortic arteries CTA with a one stop shop single high-pitch acquisition protocol provides a high image quality and success ratio along with significant reduction of radiation exposure and less contrast material, compared to that of separately acquisition protocol.

Introduction

Progression and instability of atherosclerotic plaques often occur simultaneously at multiple sites in the systemic vasculature. It has been shown that plaque formations in the carotid and coronary arteries are closely related [1] and have similar atherogenesis. Several clinical studies have demonstrated that the simultaneous assessment of atherosclerosis in the carotid, cerebral, and coronary arteries is of great importance in the clinic [2,3]. Prior investigations have suggested that 25-60% of stroke patients may have silent myocardial ischaemia at non-invasive diagnostic imaging [4] and a mortality rate due to ischaemic heart disease twice as high as that of an age-matched control group [5]. Current imaging modalities for assessment of carotid or vertebral atherosclerotic disease include Doppler ultrasound [6], magnetic resonance angiography (MRA) [7], computed tomography angiography (CTA) [8], and conventional digital subtraction angiography (DSA) [9]. Although conventional digital subtraction angiography (DSA) is still the reference standard for diagnosis because of its high spatial resolution and large field of view, it has the disadvantage of being invasive. Many institutions now use ultrasound in combination with either magnetic resonance angiography (MRA) or CTA instead of DSA to evaluate the extracranial and intracranial circulation [10,11] because these methods provide greater patient comfort and are safer and more cost-effective. With the improvements in the temporal and spatial resolution of computed tomography (CT) and in workstation technology, computed tomography angiography (CTA) is being increasingly considered as a noninvasive alternative to DSA [12]. However, CTA has not been implemented in routine imaging protocols, predominantly because of technical challenges and concerns for radiation and contrast dose [13].

Recently, Tognolini et al. [14] assessed the technical feasibility of the combined assessment of carotid and coronary arteries based on a single-bolus dual-source CTA protocol in patients with known or suspected atherosclerosis. Actually, in that study, a helical acquisition mode for the supra-aortic CTA and a prospective electrocardiography

(ECG)-triggered protocol for the coronary CTA were used with a relatively higher radiation dose of 4.3 mSv due to the limitation of temporal resolution of 83 ms of the first dual source CT. With the introduction of the high-pitch dual-source CT system, faster imaging times and improved temporal resolution of 75 ms, providing a high detector coverage through the use of two 128-section detectors, allowing coronary CTA examinations to be performed at high pitch values of up to 3.4 [15,16]. This feature allows imaging of the entire heart within a single heart beat by using a spiral acquisition mode (a "Flash Spiral" mode) that is prospectively gated by ECG and that has an effective radiation dose below 1 mSv [17]. Using high-pitch mode, Korn et al. [18] demonstrated that supra-aortic arteries CTA can obtain improved image quality while reducing dose by about 35 %. However, to our knowledge, few studies have investigated the feasibility of combined coronary and supra-aortic arteries CTA using high-pitch mode. In the present study, we investigated the feasibility of combined coronary and supra-aortic arteries CTA using high-pitch mode by evaluating the image quality and radiation doses, compared to that of separately acquisition protocol.

Materials and Methods

Study population

This study screened 211 consecutively symptomatic patients who were suspected coronary artery disease and/or cerebrovascular diseases (suffering from chest distress, chest pain, paroxysmal dizziness, fainting or suspected transient ischemic attack). The clinical decision to perform CTA was based on the history or symptoms of the patients. Patients were excluded from this study due to a body weight exceeding table limit (defined as either a body weight ≥90 kg or a body mass index (BMI) ≥30 kg/m², n=5), an impaired renal function [elevated serum

creatinine level (>1.5 mg per deciliter), creatinine clearance <60 ml per minute, n=1], hypersentivity to iodine contrast (n=1), failure to reach a target heart rate 65 bpm after pre-medication (n=8) or irregular heart rate (n=3). Twenty-nine patients did not agree perform coronary and carotid-cerebrovascular CTA simultaneously were excluded from this study too. Other exclusion criteria included: cardiac surgery or intervention within 6 months, pregnancy, stents, bypass graft, or Agatston score >800. Finally, a total of 164 patients were included in this study. Each group of 82 patients were randomly assigned in a 1:1 fashion to one of high-pitch combined coronary and supra-aortic arteries CTA acquisition protocol or separately acquisition protocol using high-pitch mode coronary CTA and Dual-energy mode carotid-cerebrovascular CTA (Figure 1). The study was approved by the institutional review board of the hospital and informed consent was obtained from each patient after the nature of the procedure had been fully explained. Patient demographics and characteristics are summarized in (Table 1).

Premedication

All patients with a presenting heart rate >60 bpm received 50 mg metoprolol orally (Beloc; AstraZeneca, Zug, Switzerland) 60 minutes before the scan started to achieve a heart rate of ≤ 65 bpm. The heart rate was lowered to achieve diagnostic image quality in all coronary segments in single diastolic reconstructions. Furthermore, all patients received 0.8 mg nitroglycerin aerosol e (Shandong Jingwei Pharma, China) sublingually prior to coronary CTA.

CT acquisition protocols

Imaging was performed with a high pitch dual-source CT system (Definition Flash, Siemens Healthcare, Forchheim, Germany). The scan protocols for the CT examinations were as follows: In Group A, the
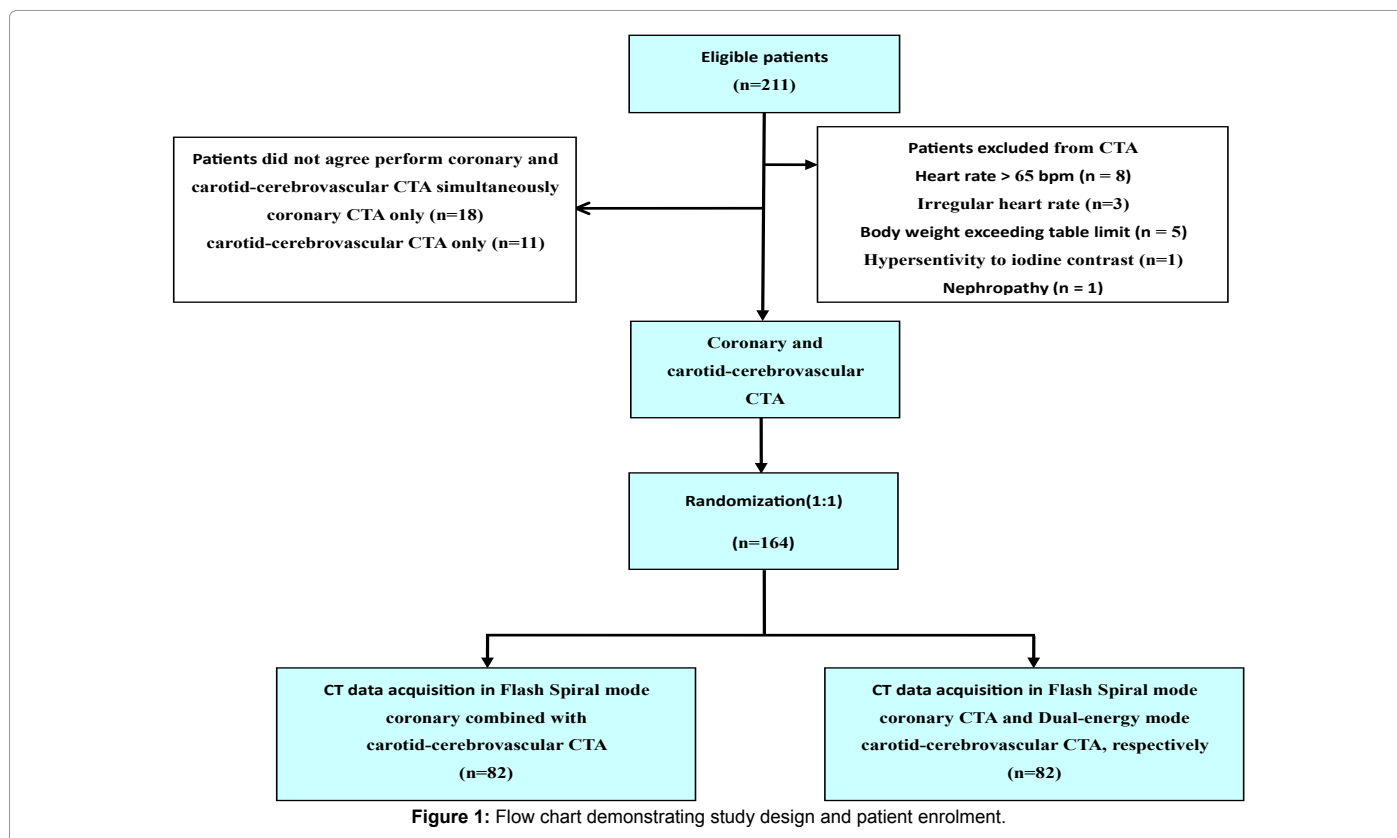

Figure 1: Flow chart demonstrating study design and patient enrolment.

	Group A (n=82)	Group B (n=82)	P value
Age (y)	53 ± 10	55 ± 11	0.51
	(range: 34-83)	(range: 30-80)	
Female patients (n, %)	35 (-42.7%)	31 (37.8%)	0.63
BMI (kg/m2)	22.15 ± 2.0 (range: 19.8-27.5)	22.74 ± 2.2 (range: 19.8-28.4)	0.1
HR (bpm)	62 ± 5	60 ± 4	0.08
	(range: 45-65)	(range: 46-65)	
Hypertension	32 (-39%)	36 (43.9%)	0.64
Hyperlipidaemia	48 (-58.5%)	44 (53.7%)	0.63
Diabetes mellitu	23 (-28%)	18 (22.0%)	0.47
Family history of CAD	8 (9.8%)	10 (12.2%)	0.8
Smoking	28 (-34.1%)	25 (30.5%)	0.74
Scan length (cm)	463.39 ± 36.06	464.12 ± 36.35	0.89
	(range: 416-744)	(range: 414-538)	
Scan time (ms)	679.88 ± 48.41	887.22 ± 67.24	0.001
	(range: 575-785)	(range: 735-1024)	
DLP(mGy.cm)	197.05 ± 16.04	416.45 ± 22.36	<.001

Abbreviations: BMI=body mass index, HR=heart rate, bpm=beats per minute, CAD=coronary artery disease, DLP= dose-length product.

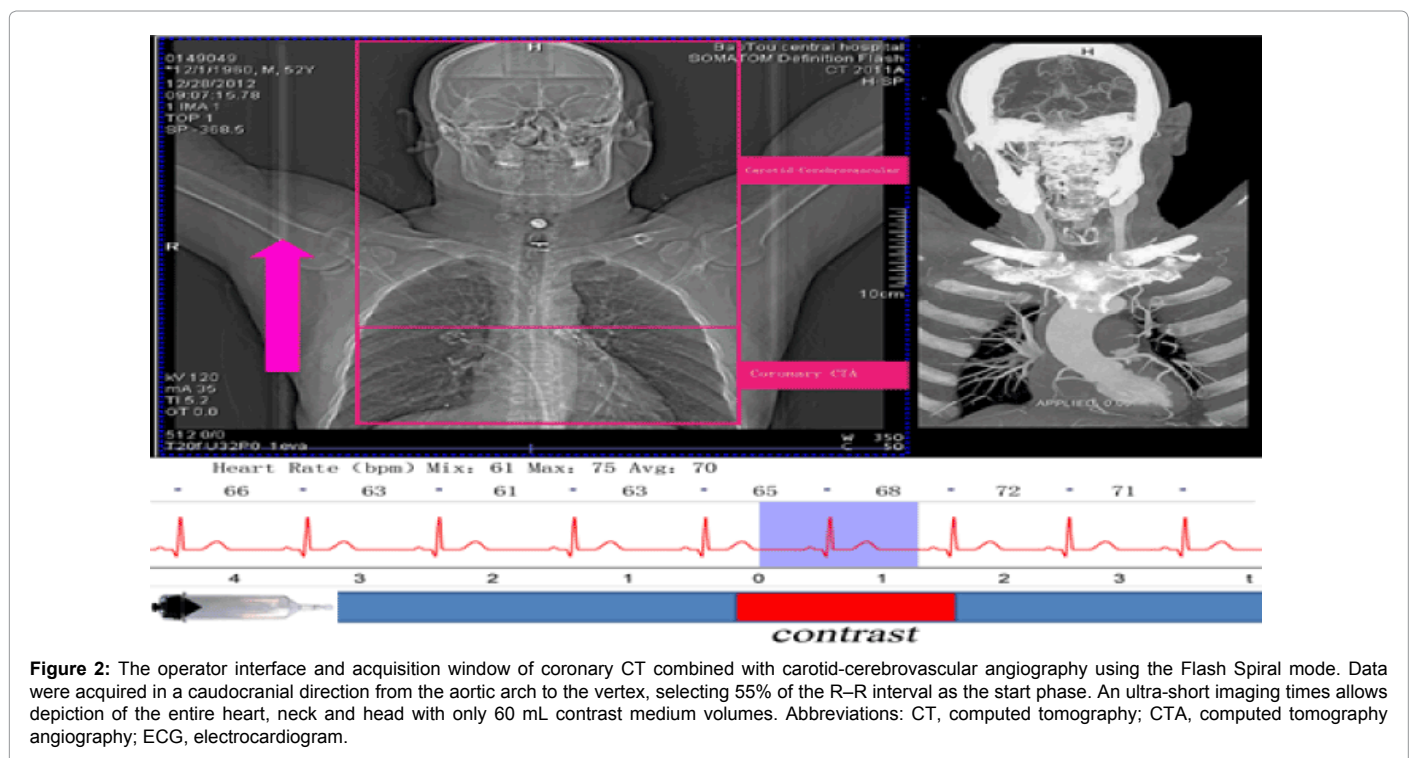**Table 1:** Patient demographics and CTA characteristics.

Figure 2: The operator interface and acquisition window of coronary CT combined with carotid-cerebrovascular angiography using the Flash Spiral mode. Data were acquired in a caudocranial direction from the aortic arch to the vertex, selecting 55% of the R–R interval as the start phase. An ultra-short imaging times allows depiction of the entire heart, neck and head with only 60 mL contrast medium volumes. Abbreviations: CT, computed tomography; CTA, computed tomography angiography; ECG, electrocardiogram.

patients were scanned in a caudo-cranial direction from the diaphragm to the vertex using the Flash Spiral mode (Figure 2), in Group B, the coronary CTA imaging was acquired using high pitch acquisition mode with a caudo-cranial direction ranging from 2 cm below the level of the tracheal bifurcation to the diaphragm and the carotid-cerebrovascular CTA imaging was acquired using a dual-energy mode with a caudo-cranial direction from the first cervical vertebra to the vertex [19]. The following acquisition parameters were used: Detector collimation, 2 × 64 × 0.6 mm; slice acquisition, 2 ×128 × 0.6 mm by means of a z-flying focal spot, with a gantry rotation time of 280 ms. The tube voltage and tube current were set as follows: high pitch mode: pitch 3.4, tube current 370 mAs per rotation, and tube voltage 100 Kv. Dual-energy mode: pitch 1.2, tube current 104-158/91-158 per rotation, and tube voltage Sn140/100 Kv. The contrast agent (Omnipaque 350 mgI/ml; GE Healthcare, USA) was intravenously injected through the antecubital vein by a power injector (SCT-210, Medrad Incorporated, Indianola, PA, USA) with a 20-gauge needle. Contrast-agent application was controlled by the bolus-tracking technique in the ascending aorta (signal attenuation threshold, 100 HU). Data acquisition was initiated after threshold was reached in the ascending aorta, with a mean delay of 8 seconds. For patients in Groups A, a total of 60 ml of contrast agent was used, followed by 60 ml of saline solution at flow rates of 5 ml/s. For patients in Group B, 60 ml of contrast agent followed by 60 ml of saline solution at flow rates of 5 ml/s for coronary CTA and 40 ml of

iohexol was injected at a flow rate of 5 ml/s and was followed by a 40-ml saline chase for carotid-cerebrovascular CTA.

CTA data analysis

All images were transferred to an external workstation (MMWP, Siemens) for data analysis. The images were reconstructed by using a section thickness of 0.75 mm and a medium-smooth tissue convolution kernel (B26f). The reconstruction interval was 0.4 mm. Curved planar reformatting (CPR), maximum intensity projection (MIP), multiplanar reformatting (MPR) and volume rendering (VR) were used to evaluate the carotid, cerebrovascular, and coronary arteries [20]. All images were evaluated by 2 independent readers (with 2 and 5 years' experience in cardiovascular and cerebrovascular imaging), who were blinded to the clinical information and the scan protocols. When there was a discrepancy between the evaluations of the 2 readers, a joint reading session was used to reach consensus. Coronary segments were defined in accordance with the American Heart Association (AHA) standards: [21] Segments 1 to 4 included the right coronary artery (RCA), segment 5 included the left main artery (LM), segments 6 to 10 included the left anterior descending artery (LAD), segments 11 to 15 included the left circumflex artery (LCX), and segment 16 included the intermediary artery.

The objective image quality

As objective parameters of image quality, the mean CT attenuations, image noise, signal-to-noise ratio (SNR) and contrast-to-noise ratio (CNR) were measured and calculated. The mean CT attenuations of the coronary arteries were measured by manually identifying a region of interest (ROI) in the left main artery (LM) that avoided calcifications, plaques, and stenoses. The mean CT attenuations of the intracranial arteries were measured by manually placing a region of interest (ROI) in the proximal sections of the common and internal carotid arteries, in the M1 segment of the middle cerebral artery, and in the V4 segment of the vertebral artery. SNR were calculated by dividing vessel attenuation in HU by its SD. The vessel contrast was defined as the difference in the mean attenuation (in HU) between the contrast-enhanced lumen of the vessel and the the adjacent perivascular fat. CNR was defined as the ratio of vessel contrast to image noise [22]. The vessel contrast of a coronary artery was defined as the difference in the mean attenuation (in HU) between the contrast-enhanced lumen of the vessel and the perivascular tissue. Image noise was defined as the standard deviation of the attenuation value in the ROI. The CNR was defined as the ratio of vessel contrast to image noise [22].

The subjective image quality

The images of the coronary, carotid and cerebral arteries were rated on a 4-point scale [23] by using axial source images and multi-planar reformations as follows: 1=excellent, with very sharp edges and high subjective contrast-to-noise ratio; 2=good, with restrictions due to minimal blurring or slightly suboptimal subjective contrast-to-noise ratio; 3=moderate but still diagnostic, with considerable restrictions due to vessel edge blurring or markedly suboptimal subjective contrast-to-noise ratio; 4=non-diagnostic, with unacceptable blurring or subjective contrast-to-noise ratio [18].

Estimation of radiation dose

The volume CT dose index and dose-length product (DLP) were recorded automatically at the end of each examination for each scan that was acquired. The effective radiation dose (in mSv) was estimated by multiplying the DLP by a conversion factor (the k value) in accordance with the guidelines on quality criteria [24]. The values of k are dependent only on the region of the body that is being scanned (k=0.014 mSv.mGy^{-1}.cm^{-1} for cardiovascular imaging; k=0.0031 mSv.mGy^{-1}.cm^{-1} for the head and neck).

Statistical analysis

Continuous variables are expressed as the means ± standard deviations and categorical variables are expressed as frequencies or percentages. A P value below .05 was considered statistically significant. All statistical analyses were performed with commercially available software (SPSS, release 17.0, SPSS, USA).

Age, BMI, scan time, and scan length of the groups were compared by 1-way analysis of variance. The mean CT attenuations, image noise, CNR, mean image quality grading, and effective radiation dose were compared between group A and group B or group A and group C with the unpaired t test. Differences in the proportions of image quality grading between the 2 groups were evaluated with the 2 test. The inter-observer agreement for the image quality scores between the two radiologists were evaluated using the Cohen's kappa statistics (kappa>0.81: excellent agreement; kappa=0.61–0.80: good agreement; kappa=0.41–0.60: moderate agreement; kappa=0.21–0.40: fair agreement; kappa <0.20: poor agreement). Still diagnostic, with considerable restrictions due to vessel edge blurring or markedly suboptimal subjective contrast-to-noise ratio; 4=non-diagnostic, with unacceptable blurring or subjective contrast-to-noise ratio [18].

Results

Patient and coronary CTA characteristics

All examinations were performed without complications during or after the procedure. Comparisons of demographic data for the patient groups are listed in (Table 1). No significant difference was found for all demographic parameters among the two groups.

Objective image quality

The objective image quality of the coronary and supra-aortic arteries was evaluated based on segments. The average enhancement and image noise of supra-aortic arteries in group A were significantly higher than that of group B. The SNR measurements in the intra-cranial and extra-cranial carotid arteries did not show a statistically significant difference (all P > 0.05), and neither did the CNR measurements (all P > 0.05), except common carotid arteries (P=0.01). Similarly, the SNR and CNR of ascending aorta did not demonstrate a statistical difference. The enhancement values, image noise, SNR and CNR measurements are reported in (Table 2).

Subjective image quality

In each patient, the subjective image quality assessment of coronary was conducted based on the analysis of segments. In total, 2254 coronary segments (Group A, 1125 segments; Group B, 1129 segments) were evaluated. The inter-observer agreement for the image quality scores was excellent (kappa=0.91). No significant difference was found for the mean image quality score between the two groups with regard to each score rate (1.07±0.33 versus 1.05±0.27, P=.14). Three patients in Group A and 2 patients in Group B had non-diagnostic images due to motion artifacts. The difference in the percentage of non-diagnostic coronary artery segments between the two groups was also not significant (segment-based analysis: 0.44% versus 0.18%, P=0.25; patient-based analysis: 3.66% versus 2.4%, P=0.65; Table 3).

The subjective image quality assessment of carotid and cerebral

	Group A (n=82)	Group B (n=82)	P value
CT attenuation（HU）			
AsAo root	455.83 ± 85.59	326.55 ± 49.68	<.01
CCA	519.37 ± 92.95	372.25 ± 74.36	<.01
ICA	488.82 ± 102.18	418.87 ± 68.48	<.01
M1	466.09 ± 85.77	384.29 ± 73.21	<.01
V4	463.53 ± 92.28	376.57 ± 69.70	<.01
Image noise			
AsAo root	24.19 ± 5.50	16.59 ± 2.68	<.01
CCA	15.71 ± 5.50	12.65 ± 3.29	<.01
ICA	18.74 ± 8.71	8.34 ± 3.41	<.01
M1	26.80 ± 16.39	18.53 ± 7.99	<.01
V4	22.34 ± 8.05	16.03 ± 9.54	<.01
SNR			
AsAo root	20.20 ± 7.47	20.32 ± 4.81	0.91
CCA	37.98 ± 21.47	30.75 ± 10.92	0.01
ICA	29.75 ± 13.46	32.41 ± 10.79	0.19
M1	25.28 ± 13.51	24.70 ± 13.49	0.79
V4	25.11 ± 16.05	28.72 ± 13.63	0.13
CNR			
AsAo root	24.45 ± 8.40	26.26 ± 5.95	0.13
CCA	45.04 ± 14.80	38.79 ± 13.31	0.05
ICA	35.76 ± 16.78	40.19 ± 12.86	0.06
M1	27.92 ± 17.25	30.96 ± 16.55	0.26
V4	28.89 ± 15.04	32.85 ± 14.18	0.09

Abbreviations: AsAo=Ascending aorta; LM=the left main artery; CCA=common carotid arteries; ICA=internal carotid artery; M1=proximal middle cerebral artery; V4=segments of the vertebral artery.

Table 2: The comparison of quantitative measurement of image quality between two groups.

	Group A (n=82)	Group B (n=82)	P value
Image quality scores of the coronary arteries			
Image quality scores	1.07 ± 0.33	1.05 ± 0.27	0.14
Nondiagnostic segments (%, n/n)	0.44% (5/1125)	0.18% (2/1129)	0.25
Nondiagnostic cases (%, n/n)	3.66% (3/82)	2.4% (2/82)	0.65
Image quality scores of the supra-aortic arteries (%, n/n)			
1 point	95.1% (78/82)	90.5% (76/82)	0.37
2 points	3.7% (3/82)	4.9% (4/82)	1
3 points	1.2% (1/82)	2.4% (2/82)	1
4 points	0	0	—

Table 3: The comparison of qualitative analysis of image quality between two groups.

arteries was based on the analysis of patients. The inter observer agreement in the assessment of image quality was good (kappa=0.68). As shown in (Table 3), 95.1% (78/82) supra-aortic arteries were scored 1 point and 90.5% (76/82), respectively in the two groups (P=0.37). Three of 82 (3.7%) and 4 of 82 (4.9%) cases were scored as 2 point (P=1.00). The intracranial and cervical arteries were 100% diagnostic (rated good or excellent) in the two groups. The representative imaging of the image quality (Point 1-4) is displayed in (Figure 3).

Representative examples of coronary and supra-aortic arteries CTA acquired with the high pitch combined carotid and coronary arteries protocol were displayed in (Figures 4 and 5).

Prevalence of vascular disease

Thirty-nine out of 82 (47.5%) patients in group A and 42 patients (51.2%) in group B were detected stenosis in either supra-aortic or coronary arteries. Coronary and supra-aortic arteries stenosis could be excluded in 52.44% (43/82) of patients in the combined acquisition protocol group and 48.7% (40/82) in the common protocol group. In group A, 12 14.6% (12/82) patients suffered from coronary artery
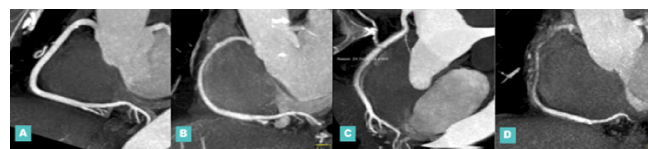

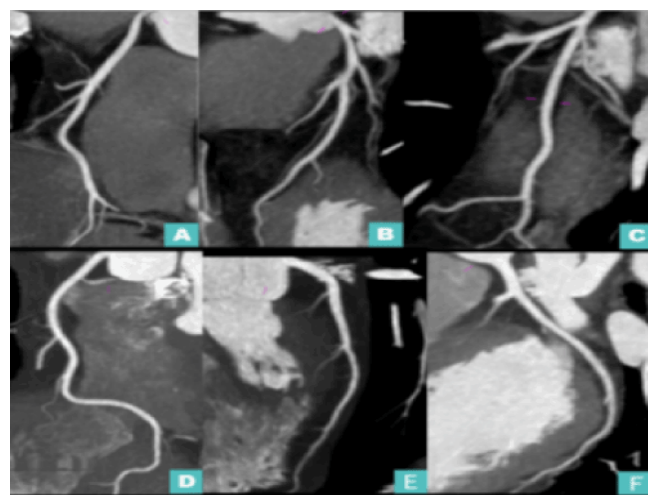**Figure 3:** The representative imaging of the image quality (Point 1-4).

Figure 4: The side-by-side comparison of the subjective image quality of coronary between Group A and B. Curved reformations of the right coronary artery (group A: figure A; group B; figure D), left anterior descending artery (group A: figure B; group B: figure E) and left circumflex artery (group A: figure C; group B: figure F) did not show motion artifacts (score 1).
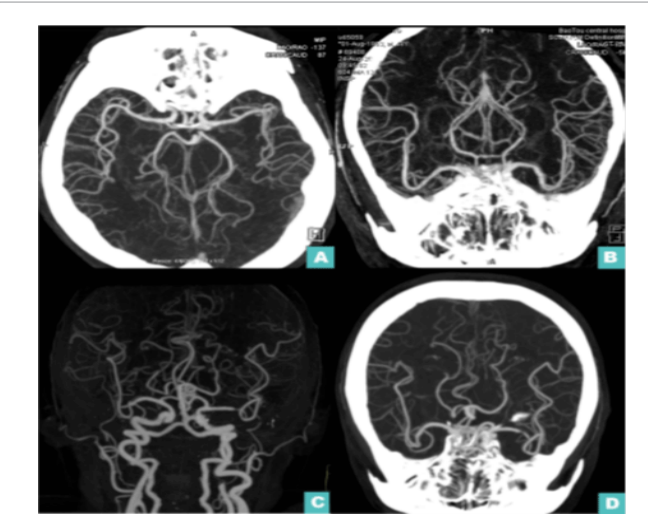

Figure 5: The comparison of the subjective image quality of supra-aortic arteries between Group A (figure A, B) and B (figure C, D). As shown, the subjective image quality of supra-aortic arteries in the two groups were both excellent (scored 1 point).

stenosis complicated with cerebral artery stenosis, of which 9 were of moderate, 3 of severe coronary and cerebral artery stenosis. In group B, a total of 14 patients were detected plaque and stenosis both in supra-aortic and coronary arteries vascular.

Radiation exposure

Significant difference was found between the two groups for the dose-length product (P<0.01), while the scan range was not significantly different between the two groups (P=0.89) (Table 1). The effective radiation dose was 1.36 ± 0.37 mSv (range, 0.88-2.58 mSv) in group A and 2.39 ± 0.38 mSv (range, 1.42-3.00 mSv) in group B (P<0.01).

Discussion

Our study demonstrates that one stop shop high-pitch CTA of combined coronary and supra-aortic arteries provides a high image quality and success ratio along with significant reduction of radiation exposure and less contrast material, compared with common protocols.

The association between atherosclerotic disease of carotid and coronary vessels is known [25] although the association between patterns of development and severity of lesions in different vascular districts is less understood. Prior observational studies have shown that imaging is able to reclassify intermediate-and low-risk Framingham Risk Score patients into higher-risk groups and, therefore, highlights the importance of imaging-based strategies for risk-modifying interventions and adherence to treatment [26]. It appears that an easy to employ technical method for CTA assessment of both vascular territories may be valuable for identification of patients with increased vascular risk. In 2010, Furtado et al. [27] published a triple rule-out protocol for acute ischaemic stroke performed on a 64-detector system. In their study, a series of 120 patients acquired adequate image quality including the intracranial and cervical arteries, aortic arch, cardiac chambers and walls, and coronary arteries. However, their protocol consisted of many phase, including non-contrast brain CT, perfusion CT series of the brain, CTA of the brain, neck, and heart with a mean DLP for the head and neck of 726.4 ± 41.5 mGy*cm and 374.7 ± 28.9 mGy*cm for the cardiac. Recently Tognolini et al. [14] assessed the technical feasibility of the combined assessment of carotid and coronary arteries in 33 patients. In their study, actually, the protocol consisted of two phase: a helical acquisition mode for the supra-aortic CTA and a prospective ECG-triggered protocol for the coronary CTA and the radiation dose was 4.3 mSv. High-pitch spiral coronary CTA is a new, prospectively ECG-triggered, high-pitch scan mode that was developed specifically for a dual-source CT system. It allows complete acquisition of the heart within a single cardiac cycle and results in very low radiation exposure [28]. Korn et al. [18] demonstrated that high-pitch CTA of supra-aortic arteries can obtain improved image quality while reducing dose by about 35%. The results of the present study suggest that the high-pitch protocol has the potential for comprehensive and time-efficient CT imaging of both carotid and coronary artery territories with very low radiation dose. Our preliminary data demonstrated that about 47.5% of asymptomatic patients had atherosclerotic disease of the coronary or supra-aortic arteries and 14.6% also presented with both in coronary or supra-aortic arteries.

In the present study, we compared the objective image quality and subjective image quality of image obtained from high-pitch combined coronary and carotid-cerebrovascular CTA to that of common protocol. Although the image noise of this protocol was higher than that of common protocol, the SNR and CNR were comparable. The CNR of supra-aortic arteries in this study was better than that of reported of

9.95-21.3 with single-source CT (120 kV), 6.8-23 in dual-energy CT (80 kV/140 kV) and 8.8-20 with high-pitch protocol (120 kV) [29] in MSCT neck imaging. The average SNR (20.2-37.7) in this study was lower than that of reported (26.3-100.4) [18] using high-pitch protocol in carotid and cerebral arteries. The reason of the difference may be due to the tube voltages were different in the two studies (120 kV protocol in the reported study while 100 kV in this study). Comparable to the results of previous studies [18,30], the overall image quality score of cerebral arteries in our investigation was generally considered to be high, at acceptable image quality score. The results indicated that the average image quality of both vascular districts of coronary and supra-aortic arteries obtained from high-pitch protocol were high and diagnostic. It demonstrates how high-pitch protocol virtually freezes transmitted movement and, thereby, significantly improves image quality of vessels.

A considerable asset to the high-pitch approach is its potential for considerable reduction of radiation dose. In previous studies, exposure was consistently reduced to below 1.0 mSv for cardiac CTA by lowering the tube voltage to 100 kVb [31]. In this study, the average effective radiation dose reduced about 68% compared to reported (4.3 mSv) [14] and was significantly lower than that of Furtado et al. [28] reported (the mean DLP of 726.4 ± 41.5 mGy*cm for head and neck and 374.7 ± 28.9 mGy*cm for cardiac). Further, iterative reconstruction algorithms enable data acquisition protocols using lower tube current settings, resulting in substantially reduced radiation exposure levels [32].

Another field for potential modification of our high-pitch CTA protocol is the delivery of contrast material. The high-pitch mode may allow a small contrast bolus at no cost to image quality for coronary combined with carotid-cerebrovascular CTA because of ultra-short imaging times. Recently, Lembcke et al. [33] stated that high pitch dual-source CTA can be performed with contrast medium volumes of 40 ml in men or 30 ml in women due to a significant reduction in acquisition time. Takeyama et al. [34] reported using 40 ml of contrast medium volume can produce the best performance quantitatively and qualitatively at the internal carotid artery for cerebral CTA with a 64-MDCT system. Previous studies have reported that the optimal vascular enhancement of the carotid and coronary vessels should be >150 and >250 HU, respectively [35,36]. The average vascular enhancement obtained with the present protocol (60 ml) resulted in an average lever over 455.83 Hu. Our results demonstrate that the high-pitch protocol presented a higher arterial contrast enhancement both in carotid and cerebral arteries. It revealed a higher image contrast for vessels scanned with this CTA protocol. Therefore, 60 ml contrast medium volumes injection protocol presented here appears to work well in high-pitch protocol for coronary combined with carotid-cerebrovascular CTA. It should be noted that the data must been acquired in a caudo-cranial direction from the aortic arch to the vertex because the diastolic time window of limited cardiac motion is quite long and suffices to scan the entire heart without motion artifacts.

Study Limitations

Our study has several limitations. First, the use of a high-pitch protocol is associated with a number of inherent challenges. Studies have indicated that CTA with bone subtraction showed significantly better diagnostic accuracy for the detection of intracranial aneurysms as compared to that without bone subtraction. However, choosing the high-pitch protocol for carotid and cerebral CTA precludes the use of a dual-energy mode which may be beneficial for automated bone removal and more sophisticated characterization of larger plaques. Second, this

initial technical feasibility study is limited by the absence of a clearly defined reference standard such as DSA, which would have helped to better quantify the results. Additional larger studies with correlations to DSA are warranted to fully assess the comparability of the results. Third, in this study, we did not use the iterative reconstruction (IR) algorithms which enable data acquisition protocols using lower tube current settings to >150 and >250 HU, respectively [35,36]. The average vascular enhancement obtained with the present protocol (60ml) resulted in an average lever over 455.83 Hu. Our results demonstrate that the high-pitch protocol presented a higher arterial contrast enhancement both in carotid and cerebral arteries. It revealed a higher image contrast for vessels scanned with this CTA protocol. Therefore, 60 ml contrast medium volumes injection protocol presented here appears to work well in high-pitch protocol for coronary combined with carotid-cerebrovascular CTA. It should be noted that the data must been acquired in a caudo-cranial direction from the aortic arch to the vertex because the diastolic time window of limited cardiac motion is quite long and suffices to scan the entire heart without motion artifacts (Figure 1) reduce radiation exposure levels. Future studies should be required to compare the Filter Back Projection (FBP) and IR reconstructions in order to improve the image quality of this protocol using lower tube current settings.

Conclusion

The results of our study indicate that the combined coronary and supra-aortic arteries CTA with a one stop-shop single high-pitch acquisition protocol provides a high image quality and success ratio along with significant reduction of radiation exposure and less contrast material, compared to that of separately acquisition protocol.

Conflict of Interest

All authors have reviewed the final edition of the manuscript and approve it for publication. This manuscript has not been published previously and is not being considered concurrently by another publication. The authors disclose no conflicts.

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