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ORIGINAL ARTICLE

Preliminary clinical application of an adaptive iterative statistical reconstruction algorithm inhead and neck computed tomography angiography with low tube voltage and a low concentration of contrast medium

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Abstract

Objective To evaluate the feasibility of using a low concentration of contrast medium (Visipaque 270 mgI/mL), low tube voltage, and an advanced image reconstruction algorithm in head and neck computed tomography angiography (CTA).

Methods Forty patients (22 men and 18 women; average age 48.7 ± 14.25 years; average body mass index 23.9 ± 3.7 kg/m^2) undergoing CTA for suspected vascular diseases were randomly assigned into two groups. Group A ($n = 20$) was administered 370 mgI/mL contrast medium, and group B ($n = 20$) was administered 270 mgI/mL contrast medium. Both groups were administered at a rate of 4.8 mL/s and an injection volume of 0.8 mL/kg. Images of group A were obtained with 120 kVp and filtered back projection (FBP) reconstruction, whereas images of group B were obtained with 80 kVp and 80% adaptive iterative statistical reconstruction algorithm (ASiR). The CT values and standard deviations of intracranial arteries and image noise on the corona radiata were measured to calculate the contrast-to-noise ratio (CNR) and signal-to-noise ratio (SNR). The beam-hardening artifacts (BHAs) around the skull base were calculated. Two readers evaluated the image quality with volume rendered images using scores from 1 to 5. The values between the two groups were statistically compared.

Results The mean CT value of the intracranial arteries in group B was significantly higher than that in group A ($P < 0.001$). The CNR and SNR values in group B were also statistically higher than those in group A ($P < 0.001$). Image noise and BHAs were not significantly different between the two groups. The image quality score of VR images of in group B was significantly higher than that in group A ($P = 0.001$). However, the quality scores of axial enhancement images in group B became significantly smaller than those in group A ($P< 0.001$). The CT dose index volume and dose-length product were decreased by 63.8% and 64%, respectively, in group B ($P < 0.001$ for both).

Conclusion Visipaque combined with 80 kVp and 80% ASiR provided similar image quality in intracranial CTA with 64% radiation dose reduction compared with the use of Iopamidol, 120 kVp, and FBP reconstruction.

Key words: low concentration contrast medium; head and neck computed tomography angiography; adaptive iterative statistical reconstruction algorithm

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Computer tomography angiography (CTA) is a well-established minimally invasive diagnostic procedure that can be performed immediately. CTA has an essential role in the diagnosis of patients with cerebral aneurysms,

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subarachnoid hemorrhage (SAH), or intracranial artery atherosclerotic stenosis. However, the risk of acquiring radiation-induced cancer from CT examinations has been reported [1]. Many techniques have been proposed to effectively reduce radiation exposure in patients. One of these techniques is combining the use of low tube voltage and advanced reconstruction algorithms, such as the adaptive statistical iterative reconstruction (ASiR) algorithm [2], to improve image contrast and reduce image noise. Additionally, the discomfort and potential negative effects of contrast medium with different osmolarities on renal function have also been the subject of debate. Although there are no conclusive data indicating whether there is a definite difference in renal tolerance between iso-osmolar contrast medium (IOCM) and low-osmolar CM (LOCM) [3–4], a recent study has indicated that improvement of the contents of CM has resulted in less frequent and reduced discomfort in patients undergoing IOCM, resulting in less pain and warmth during intravascular administration compared with that in patients undergoing LOCM [5].

Earlier studies have focused on the use of low tube voltages and high concentrations of contrast medium for radiation dose reduction. In this study, the IOCM Vispaque270 was used in combination with 80 kVp and 80% ASiR to examine the capacity for reducing radiation and contrast medium dosages in head and neck CTA examinations.

Materials and methods

Patients

The institutional review board approved this study with waiver of patient consent, and the equipment used in this study was commercially available. Between November 2012 and March of 2013, all patients with headache, suspected intracranial aneurysms, or SAH were enrolled in our clinical study. All examinations were performed for clinical purposes. The exclusion criteria for this study were as follows: (1) patients with allergy to iodinated CM, renal insufficiency (serum creatine level of 1.5 mg/dL), severe heart failure, or previous history of asthma; (2) patients with a body mass index exceeding 30 kg/m^2 or without venous access in the right upper limb; and (3) patients with neuro-intervention or intracranial surgery. Finally, 40 patients (22 men and 18 women; average age 48.7 ± 14.25 years; average body mass index 23.9 ± 3.7 kg/m^2) were included and enrolled randomly into two groups (groups A and B; n = 20 patients per group). There were no significant differences in patients' ages, body weights, and body mass indexes between groups ($P > 0.05$; Table 1).

CT protocol

All head and neck CTA examinations were performed with a 64s-MDCT scanner (Discovery CT750 HD; GE Healthcare, USA). Patients were examined in the supine position with their arms alongside the body and their heads tilted slightly forward. The acquisition was performed in the caudocranial direction, with the scan range spanning the entire head and neck from the aortic arch up to the calvarium. Patients were scanned with 120 kVp tube voltage in group A and 80 kVp tube voltage in group B. The other scanning parameters were the same for both groups: pitch, 0.984:1; gantry rotation time, 0.5 s; tube current, 400 mA; beam collimation, 64 × 0.625 mm. The reconstruction field of view was 23 cm, and the reconstruction section thickness was 0.625 mm. Images in group A were reconstructed using the conventional FBP algorithm, and images of group B were reconstructed using ASiR with 80% blending.

The test bolus technique was used with a small amount of CM and a low radiation dose (120 kVp, 40 mAs) to obtain accurate information about the CM arrival time for individual circulation. Dynamic monitoring scans were positioned at the level of the fourth cervical vertebra. The delay between each monitoring scan acquisition was 2 s. Acquisition of dynamic monitoring scans started 5 s after the beginning of the injection of intravenous contrast material (15 mL of CM followed by 10 mL of saline flush was administered at a flow rate of 4.8 mL/s). Scans continued until CM appeared as hyperattenuating spots in the vessels. A region of interest (ROI) as large as the carotid artery was drawn inside the lumen by operators to generate an enhancement curve, which showed the

Table 1 Patient characteristics and scanning and injection protocols

Parameter	Group A	Group B
Patient characteristic		
Sex ratio (men/ women)	9/11	13/7
Age (years)*	47.6 ± 13.7	49.8 ± 14.8
Body weight (kg)*	63.0 ± 11.2	63.8 ± 10.3
Body mass index (kg/m^2)*	24.2 ± 3.9	23.6 ± 3.5
Scanning parameters		
Tube voltage (kVp)		
Tube current (effective mAs)	120	80
Rotation time (s)	400	400
Pitch	0.5	0.5
Injection parameters	0.984:1	0.984:1
Iodine concentration (mg/mL)	370	270
Volume (mL/kg)	0.8	0.8
Flow rate (mL/s)	4.8	4.8
Reconstruction parameters		
Reconstruction algorithm	Filtered back projection	80% ASiR*
Radiation exposure		
CTDIvol (mGy)	35.4 ± 0.2	12.8 ± 0.1**
DLP (mGy-cm)	1394.1 ± 0.7	502.3 ± 0.2**

* Data are expressed as mean ± standard deviation (SD); ** Indicating a statistically significant difference ($P < 0.05$)

time needed to reach the peak of enhancement of the test bolus. The time to peak test bolus contrast enhancement was used to estimate scan delays for the full bolus diagnostic CTA. The scan delay was calculated to be equal to the time to peak enhancement plus an additional diagnostic delay (8 s in group A). Considering the use of different concentrations of CM and the varying viscosities of these CMs, the scan delay of group B was 2 s less than that of group A. All CT examinations were performed at least 2 min after the end of the test bolus injection in order to minimize venous attenuation because of the effects of the test bolus injection.

CM

The CMs Iopamidol (Iopamiron, 370 mgI/mL; Shanghai, China) and Iodixanol (Visipaque, 270 mgI/mL; Ireland) were injected in groups A and B, respectively, with a power injector (Medrad Inc., Stellant D, USA) with and injection volume of 0.8 mL CM/kg body weight followed by a 20-mL saline flush. According to Lee *et al*, the right antecubital vein provides the shortest path, resulting in fewer streak artifacts caused by flow in left brachiocephalic vein [6]. Our venous access was in the right arm via a 20-gauge venous catheter. All CM types were preserved in an incubator at 35 °C. A recent study showed that the use of warmed CM results in higher enhancement and can improve patient tolerance and compliance [7–8]. The injection rate was the same as the test bolus at 4.8 mL/s.

Image analysis

To analyze the entire head and neck vascularity, source images were loaded on an advanced workstation (Adw4.5; GE Healthcare) and displayed with a window setting of 350/40 HU. For quantitative analysis, the arterial attenuation value and image noise were measured in a 6-mm^2 circular region-of-interest (ROI) placed in five segments: (1) the anterior cerebral artery (ACA) at the A1 segment; (2) the middle cerebral artery (MCA) at the M1 segment; (3) the posterior cerebral arteries (PCAs) at the P1 segment; (4) the internal carotid arteries (ICAs) at the cervical segment; and (5) the distal vertebral arteries. Mean values of the left and right side were calculated for each patient. A region in the corona with relatively homogeneous density was selected as the background for the brain. The mean CT number and standard deviation were noted. The ROIs were drawn by a single radiologist. The signal-to-noise ratios (SNRs) and contrast-to-noise ratios (CNRs) of the arteries were calculated. The SNR was calculated by dividing the mean enhancement of the artery (CT value) by the standard deviation (image noise) in the corona. The CNRs for arteries relative to brain parenchyma were described using the following equation [9]:

$$CNR = (CT_{artery} - CT_{background}) / SD_{background}$$

where CT_{artery} is the mean attenuation for the vessel of interest; $CT_{background}$ is the mean attenuation for the background the corona radiata; and SD is the image noise.

The beam-hardening artifacts (BHAs) around the skull base were measured in three anatomical regions (medulla oblongata, pons, and the inferior part of the frontal lobes) with areas of 3–31 cm2 and were calculated as follows:

$$BHAs =\_ \sqrt{N_0^2 - N_b^2}$$

where N_0 was the noise for the study regions, and N_b was the noise for the background [10]. Grading of image quality was performed on the same workstation as described above. One radiologist with 2 years of experience in three-dimensional image reconstruction was asked to reconstruct the volume rendered (VR) CTA images. All threshold values were adjusted to 0. Two radiologists who had more than 5 years of experience in the evaluation of head and neck CTA images assigned quality scores to all cases, which were presented in random order without any information about the kVp settings and contrast medium concentration using a five-point scale corresponded to the image quality expected with standard CTA of the head and neck. Degree of image noise, delineation of arteries in axial enhancement images, and quality of VR images, including delineation of vessels and visibility of small arterial details (based on depiction of small arteries, such as the ophthalmic, anterior communicating, posterior communicating, and superior and inferior cerebellar arteries) were evaluated. A score of 1 indicated nondiagnostic image quality; a score of 2 indicated substandard image quality; a score of 3 indicated standard image quality; a score of 4 indicated better than standard quality; and a score of 5 indicated excellent image quality.

Radiation dose assessment

The volume CT dose index (CTDIvol) and dose length product (DLP) for the two patient groups were recorded from the dose page of each CT image data set.

Statistical analysis

Statistical analyses were performed with commercially available software (SPSS, version 17.0). Statistically significant intergroup differences in the CT value, CNR, SNR, image noise, BHAs, and qualitative scores recorded by two radiologists between the two groups were analyzed using two-tailed paired *t* tests. For all studies, a difference with a *P* value of less than 0.05 was considered significant.

Interobserver agreement was measured with the κ test. The scale for the κ coefficients for interobserver agreement was as follows: less than 0.00, poor; 0.00–0.20, slight; 0.21–0.40, fair; 0.41–0.60, moderate; 0.61–0.80, substantial; and 0.81–1.00, almost perfect [11].

Results

Comparisons between groups A and B showed that the overall vascular enhancement of the head and neck arteries was significantly higher in group B (with 270 mgI/mL contrast medium, 80 kVp tube voltage, and ASiR reconstruction) than in group A (with 370 mgI/mL, 120 kVp, and FBP reconstruction), as shown in Fig. 1 ($P = 0.001$).

On a per-vessel basis, the mean intravascular enhancement was greater in group B than in group A, and the difference was statistically significant at the level of the arteries for the ICA ($P < 0.001$) and VA ($P = 0.001$), the A1 segment of the ACA ($P = 0.001$), the M1 segment of the MCA ($P < 0.001$), and the P1 segment of the PCA ($P < 0.001$; Table 2).

The CNR and SNR values for patients in group B (37.1 ± 8.5 and 41.3 ± 9.5, respectively) were significantly increased compared with those in group A (26.5 ± 3.5 and 29.7 ± 3.6, respectively; $P < 0.001$; Table 3, Fig. 2, and Fig 3). The CTDIvol and DLP values were 35.4 ± 0.2 mGy and 1394.1 ± 0.7 mGy-cm, respectively, for group A and 12.8 ± 0.1 mGy and 502.3 ± 0.2 mGy-cm, respectively, for group B. These values were decreased by 63.8% and 64%, respectively, for group B. The BHAs around the skull bones were 6.7 ± 1.8 in group A and 7.2 ± 3.6 in group B ($P > 0.05$), and the difference between the two groups was not significant. Additionally, although the image noise (SD) of group B (11.5 ± 1.4) was slightly higher than that of group A (11.1 ± 0.8), the difference was not significant.

For qualitative analysis, there was fair interobserver agreement with regard to overall image quality ($\kappa = 0.54$). The image quality scores of VR images in group B (4.2 ± 0.9) were significantly higher than those in group A (3.7 ± 0.9; $P = 0.001$; Fig. 4). However, the quality scores of axial enhancement images in group B (4.1 ± 0.6) were significantly smaller ($P < 0.001$) than those in group A (4.9 ± 0.4).

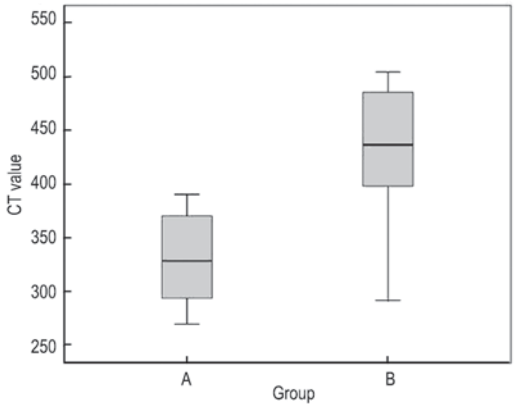

Fig. 1 The graph shows the CT values in groups A and B. The mean CT values of the overall vasculature differed significantly between groups. Group A included scanning performed at 120 kVp with 370 mgI/mL CM, and group B included scanning performed at 80 kVp with 270 mgI/mL CM. CM, contrast medium

Table 2 Intravascular enhancement in groups A and B

Head and neck artery branches	Group A	Group B	P
Internal carotid artery	433.10 ± 64.4	573.1 ± 74.0	< 0.001
Distal vertebral artery	386.5 ± 78.2	500.4 ± 85.8	< 0.05
Anterior cerebral artery	251.8 ± 44.5	346.6 ± 64.0	< 0.05
Middle cerebral artery	318.2 ± 54.2	436.5 ± 82.7	< 0.001
Posterior cerebral artery	265.7 ± 34.9	351.5 ± 76.3	< 0.001

Table 3 CT values, CNRs, SNRs, and VR scores in groups A and B

	Group A	Group B	P
CT value (HU)	330.1 ± 40.5	433.1 ± 55.9	< 0.001
CNR	26.5 ± 3.5	37.1 ± 8.5	< 0.001
SNR	29.7 ± 3.6	41.3 ± 9.5	< 0.001
VR Score	3.7 ± 0.9	4.2 ± 0.9	= 0.001
Axial image score	4.9 ± 0.4	4.1 ± 0.6	< 0.001
BHA	6.7 ± 1.8	7.2 ± 3.6	> 0.05
SD	11.1 ± 0.8	11.5 ± 1.4	> 0.05

Discussion

This is a preliminary study evaluating the image quality of head and neck CTA with a low concentration of CM (270 mgI/mL), low tube voltage (80 kVp), and ASiR reconstruction. Our result demonstrated that the use of low tube voltage effectively compensated for the reduced contrast by using a low concentration of CM. Moreover, ASiR reconstruction made it possible to decrease image noise and improve image quality with low-concentration CM and low tube voltage.

Studies have reported that a higher concentration of CM results in a higher magnitude of peak contrast enhancement [12]. Owing to its isotonicity, Iodixanol (270 mgI/mL) is thought to cause less local pain and extravasular edema. Pain and discomfort may cause patients to move, thus resulting in motion artifacts and suboptimal images. Moreover, lower-concentration CM minimizes perivenous artifacts.

The disadvantages of low-concentration CM in vessel enhancement are compensated for by the use of lower tube voltage. This is because a lower voltage increases the attenuation of iodine owing to its photoelectric effects in X-rays, particularly in scans of a high effective atomic number, such as bone, and in iodinated CM [12, 13]. In addition, using a lower voltage can reduce the radiation exposure, which protects adult patient populations, particularly for those requiring multiple or multiphase studies. However, scanning with low tube voltage will often result in an increase in image noise and the degradation of image quality.

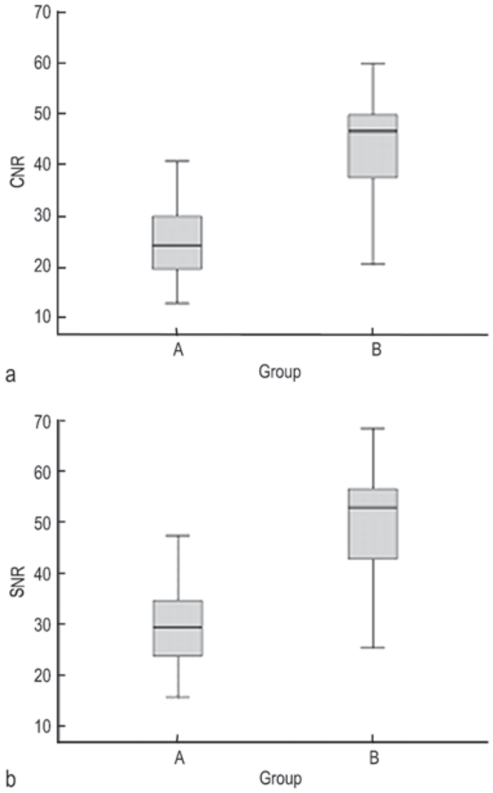

Fig. 2 The graphs show the CNR and SNR values in groups A and B. (a) The CNR values differed significantly between groups; (b) The SNR values differed significantly between groups. Group A included scanning performed at 120 kVp with 370 mgI/mL CM and FBP, and group B included scanning performed at 80 kVp with 270 mgI/mL CM and 80% ASIR. CM, contrast medium; FBP, filtered back projection; ASIR, adaptive statistical iterative reconstruction

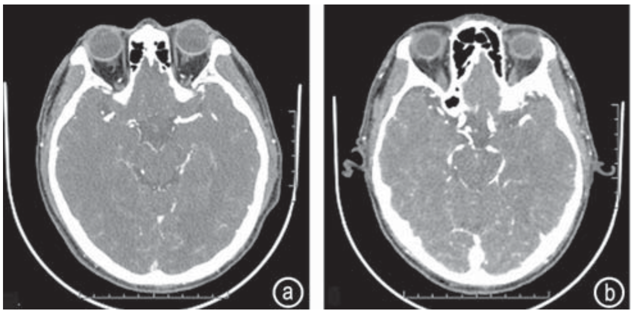

Fig. 3 Axial enhanced images of a 56-year-old woman (BMI = 21.8 kg/m^2) with suspected cerebral infarction who underwent head and neck CTA using 120 kVp and 370 mgI/mL. (a) The CT value of the middle cerebral artery was 301.2 HU; (b) A 55-year-old woman (BMI = 22.3 kg/m^2) with headache underwent head and neck CTA using 80 kVp and 270 mgI/mL. The CT value of the middle cerebral artery was 465.4 HU

Fig. 4 (a, b) VR images from a 56-year-old woman (BMI = 21.8 kg/m^2) with suspected cerebral infarction who underwent head and neck CTA using 120 kVp and 370 mgI/mL. The white arrow indicates the stenosis of a section of the right internal carotid artery; (c, d) VR images from a 55-year-old woman (BMI = 22.3 kg/m^2) with headache who underwent head and neck CTA using 80 kVp and 270 mgI/mL. BMI, body mass index; VR, volume rendered

In our study, image noise was significantly decreased on images obtained at 80 kVp due to the application of 80% ASiR, which uses information obtained from the FBP algorithm as an initial building block for image reconstruction. The ASiR model then uses matrix algebra to transform the measured value of each pixel (y) to a new estimate of the pixel value (y'). This pixel value is then compared with the ideal value predicted by the noise model. The process is repeated in successive iterative steps until the final estimated (X) and ideal pixel values ultimately converge. For this reason, ASiR is able to preserve and enhance the diagnostic capability of CT examination and then subtract noise from an image [14]. Therefore, the scheme combining low tube voltage with low-concentration CM in head and neck CTA is viable. Furthermore, although Iopamidol (370 mgI/mL) has a higher iodine concentration than Iodixanol (270 mgI/mL), it still has higher osmolarity (796 mOsm/kg H2O) than both the blood and Iodixanol (290 mOsm/kg H2O) and will absorb water, causing a dilution effect that decreases its enhancement.

In our study, the volume of CM used was based on patient weight because the strength of an individual's enhancement response to intravenously administered CM depends primarily on the patient's cardiac output and correlates inversely with body weight [15]. Therefore, determining the volume of CM based on the patient's weight may result in improved intravascular enhancement. The CT scan should be delayed appropriately. For head and neck CTA, scanning too early would result in a suboptimal enhancement, whereas scanning too late would cause venous overlap. The higher viscosity of Iopamidol (370 mgI/mL) than Iodixanol (270 mgI/mL) at 37 ℃ (9.4 versus 5.8 mPa × s, respectively) will result in lower circulation and may prohibit a fast delivery of iodine when rapid peripheral intravenous injection is desired [16]. Based on our experience from preliminary experiments, we found a 6-s delay time for Iodixanol (270 mgI/mL) and an 8-s delay time for Iopamidol (370 mgI/mL); the scanning protocol could capture the maximal arterial enhancement with minimal venous overlap. However, there were several limitations to our study. First, the scan delay for group B was based on our preliminary clinical experience after only 10 cases. Therefore, further studies are required to determine the optimal scan delay time for Iodixanol (270 mgI/mL). Second, most patients included in this study had normal cerebral and cervical arteries. Further studies are needed to assess any unique features of patients with atherosclerosis. Third, Chinese patients tend to weigh approximately 60 kg or less, and the ranges and mean body weights of these individuals are smaller than those of individuals in North America and Europe. Lastly, the volume of CM was based on each patient’s weight, and the injection rate was 4.8 mL/s. For patients with low weight and low cardiac output, the dissipation of the CM may be enhanced. Further studies are required to reduce the volume of CM and increase the injection rate.

In conclusion, the use of 270 mgI/mL contrast medium combined with 80 kVp acquisition and 80% ASiR reconstruction in head and neck CTA can provide image quality similar to that of 27% CM iodine dose reduction and 64% radiation dose reduction as compared with the conventional protocol of 370 mgI/mL, 120 kVp acquisition, and FBP reconstruction.

Conflicts of interest

The authors indicated no potential conflicts of interest.

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