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CT angiography of the neck: Value of contrast medium dose reduction with low tube voltage and high tube current in a 64–detector row CT

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AIM: To evaluate the feasibility of a low-dose contrast medium protocol for 64-detector row computed tomography angiography (CTA) of the neck using a low-tube-voltage/high-tube-current setting.

MATERIALS AND METHODS: A phantom study was performed using 64-detector row spiral CT at multiple tube voltage and current settings. Iodine contrast medium attenuation curves were acquired by processing and used to select the best contrast medium-to-noise ratio (CNR). A prospective clinical study was then performed on 84 patients requiring neck CTA. Patients were randomly divided into two groups of 42. Group A was examined using the conventional imaging protocol (120 kV, 400 mAs) and group B was examined at 80 kV and 600 mAs along with a 50% reduction in contrast medium dose. The CT dose index-volume ($CTDI_{vol}$), background noise (BN), and CNR were measured and statistically analysed. Various image quality criteria were evaluated by two senior radiologists using a qualitative five-point scale.

RESULTS: Comparing group B with A, $CTDI_{vol}$ decreased by 54% (B: 27.48 mGy, A: 59.11 mGy), however, the CNR increased by 50%. The mean attenuation, which was caused by venous streak artefacts, was significantly lower in group B than A. Qualitative image analysis found that all criteria were significantly better for group B than A.

CONCLUSION: At 64-detector row spiral CT, the low-tube-voltage/high-tube-current with low-dose contrast medium protocol was superior to the conventional protocol regarding radiation dose, venous streak artefacts, and image quality, and is feasible for CTA of the neck.

Introduction

Although computed tomography (CT) examination can produce high-quality imaging, this usually entails a trade-off in the form of increased radiation dose. Recently, there has been increased attention regarding the potential harm to patients from CT radiation, such as the higher risk of cancer.[1–4] Therefore, great importance has been attached to reducing the radiation dose.[5] Although decreasing the tube current is the most common approach to reducing the radiation dose,[6–9] unfortunately, this can decrease the contrast-to-noise ratio (CNR) of the acquired images, rendering them difficult to use for accurate diagnosis. It has been reported that scanning with a low tube voltage may reduce radiation dose without deteriorating image quality.[10–14] Using a low tube voltage can allow a reduction in contrast medium as well as radiation dose, while producing better image quality for neck CT angiography (CTA).

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Contrast media-induced nephropathy is now the major source of hospital-acquired acute renal failure.[15,16] As contrast media-induced nephropathy is associated with an increased mortality rate[17,18] and is closely related to pre-existing renal insufficiency[19,20] and the amount of contrast media delivered,[21] the smallest diagnostically appropriate amount of contrast medium is recommended in patients with chronic kidney disease.

In neck CTA, venous streak artefacts (slow-flowing contrast material in the subclavian vein, brachiocephalic vein and/or superior vena cava obscuring the origins of great vessels) present a technically challenging problem. Venous streak artefacts affect image quality and complicate image diagnosis. At present, there are few studies in the literature focusing on the reduction of venous streak artefacts. Yoon et al.[22] used 80 ml of contrast medium followed a 40 ml saline flush and de Monyé et al.[23] suggested using the craniocaudal scan direction. However, the effect on artefact reduction was not obvious.

Thus, the purpose of the present study was to evaluate the effect of a protocol using a low volume of contrast medium and a low-tube-voltage/high-tube-current product technique on radiation dose and image quality of neck CTA using 64-detector row spiral CT.

Materials and methods

Phantom study

Using tube voltages of 80, 100, 120, and 140 kV and tube currents of 100, 200, 300, 400, 500, and 600 mAs on 64-detector row spiral CT, iodine contrast medium attenuation curves were generated and analysed to determine the best CNR. This combination would then be tested in a routine clinical setting.

A cylindrical polymethylmethacrylate (PMMA) head phantom with a diameter of 165 mm was used. Six 20 mm diameter tubes filled with contrast material could be inserted into the surroundings of the phantom. A 3 cm × 4 cm piece of pork was used to fill in the middle of the PMMA tube. The six tubes were filled with 1.25, 2, 4, 8, 17, and 35 mg iodine/ml mixed solution (iohexol, 350 mg iodine/ml; 0.9% sodium chloride, injection), respectively, in an anticlockwise direction. To ensure accuracy of the experimental data, the contrast medium was free of precipitation before scanning.

The experimental images were assessed by two observers using the following process. First, a region of interest (ROI) with an area of 2 mm^2 was set to measure the radiodensity (HU) in the centre of each tube (SI1) and in the pork (SI2) under different tube voltage and tube current settings. Next, the standard deviation of the pork radiodensity was measured and set as the background noise (BN), and the data were recorded to calculate the average value using the different tube voltage and tube current settings. Then, the best CNR with the formula CNR = (SI1−SI2)/BN was determined.

Clinical study

Between May and September 2012, 84 patients scheduled to undergo neck CTA were prospectively selected. The Yangzhou Regional Ethical Review Board in Jiangsu province of China approved this study, and all participants gave informed consent. These patients were randomized into either group A or B, with 42 patients in each. For group A, the scanning parameters were 120 kV and 400 mAs, and the amount of contrast medium was 350 mg iodine/kg of body weight with a 50 ml saline flush. For group B, the scanning parameters were 80 kV, 600 mAs, and 175 mg iodine/kg of body weight, with a 50 ml saline flush.

Patients

The patients included 43 males and 41 females whose ages ranged from 22–85 years, with a median age of 59.5 years. Exclusion criteria were the following: patients who suffered from severe liver or kidney dysfunction or cardiac insufficiency; allergy to iodine contrast media; patients >85 kg in weight were not included in the study and obese patients whose body mass index (BMI) was greater than 30.[24] Group A had 22 males and 20 females whose heights ranged from 154–176 cm with an average height of 165.2 ± 11.3 cm and a weight range of 46–82 kg and average weight of 65.8 ± 17.2 kg. Group B had 21 males and 21 females whose height ranged from 153–177 cm with an average height of 164.6 ± 12.4 cm and weight ranging from 45–85 kg with an average weight of 66.2 ± 18.1 kg. Unless otherwise specified, data are means ± standard deviation.

CTA and contrast medium infusion protocols

All the patients were scanned with a 64-detector row spiral CT machine (LightSpeed VCT; GE Healthcare Yangzhou, China). Other than tube voltage and current, imaging parameters were as follows: 0.625 mm effective section thickness, 40 × 0.625 mm beam collimation, 0.984:1 helical pitch, and 0.4 s rotation time (Table 2). To ensure a consistent image quality, the CT machine was calibrated every week.

A high-pressure syringe was used to inject 15 ml iohexol (350 mg iodine/ml, Yangtze, China) and sodium chloride (15 ml, 0.9%, Yangtze, China) into the right cubital vein to measure the contrast medium peak-time of the internal carotid artery and determine the delay time. Injection of iohexol was then commenced, and was followed by a 50 ml saline flush.

Table 1
Patient characteristics between the two groups.

Variable	Group A	Group B	*p*-Value
No. of patients	42	42	
Male-to-female ratio	22:20	21:21	.64
Age (years)	58.5 ± 17.5	56.2 ± 19.1	.57
Weight (kg)	65.8 ± 17.2	66.2 ± 18.1	.45
Height (cm)	165.2 ± 11.3	164.6 ± 10.4	.21

Unless otherwise specified, data are means ± standard deviation.

Table 2
Scanning parameters for each protocol.

Parameter	Group A	Group B
Beam collimation (mm)	40 × 0.625	40 × 0.625
Effective section thickness (mm)	0.625	0.625
Helical pitch	0.984:1	0984:1
Rotation time (s)	0.4	0.4
Tube Voltage (kV)	120	80
Tube current (mAs)	400	600
$CTDI_{vol}$ (mGy)	59.11	27.48
DLP (mGy·cm)	817.3	380.1
Total amount of contrast media (mg iodine/kg)	350	175
Total amount of contrast media (ml)	50–80	25–40
Total amount of saline flush (ml)	50	50
Injection speed (ml/s)	5–6	4–5
Contrast media injection duration (s)	10–14	6–8

$CTDI_{vol}$, CT dose index-volume; DLP, dose–length product.

The data collected were transferred to the GE PACS workstation to perform post-processing. Post-processing methods include maximum intensity projection (MIP), multiple planar reformation (MPR), and volume rendering (VR).

Quantitative image analysis

A radiologist (X.R.Y., with 10 years of experience) set a circular ROI with an area of 2 mm^2 to measure the signal intensity of the ascending aorta (SI aorta), internal carotid artery (SI carotid), and vertebral artery (SI vertebral) of the patients in groups A and B and then calculated the average value of the former three (SI4) while measuring the signal intensity of the sternocleidomastoid muscle (SI SCM). Taking the standard deviation of the SI SCM as the background noise (BN), the attenuation of the bilateral sternocleidomastoid muscle was measured. To minimize bias from single measurements, the average of the measurements was calculated for each ROI and calculated the value by the following formula: SI4 = (SI aorta + SI carotid + SI vertebral)/3; CNR = (SI4−SI SCM)/BN.

Qualitative image analysis

The image quality of the CTA protocol was evaluated independently by two observers, a junior resident (Z.J.W. with 5 years of experience) and a senior interventional neuroradiologist (J.T.W. with 20 years of experience) who was blinded to the image review results. A score of 1 indicated an image quality that was too poor to use for diagnosis; a score of 2 indicated substandard image quality; a score of 3 indicated standard image quality; a score of 4 indicated better than standard image quality; and a score of 5 indicated excellent image quality. The two observers also independently scored the following image quality parameters: arterial enhancement, visibility of small arterial details (based on depiction of small arteries, such as the ophthalmic, anterior choroid, anterior and posterior communicating, and superior cerebellar arteries), venous streak artefacts, interference of venous structures (venous contamination), and image noise.

Statistical processing

Statistical analysis was performed using the SPSS 18.0 statistical software package. An independent-samples *t*-test was performed on the following aspects: arterial enhancement, venous contamination, image noise, CNR, and venous streak artefacts. The chi-square test was used to test gender. Image quality was statistically evaluated using the Mann–Whitney *U*-test.

Results

Iodine attenuation curve for the phantom study

Linear relationships were found between the iodine concentration and 80, 100, 120, and 140 kV tube voltages

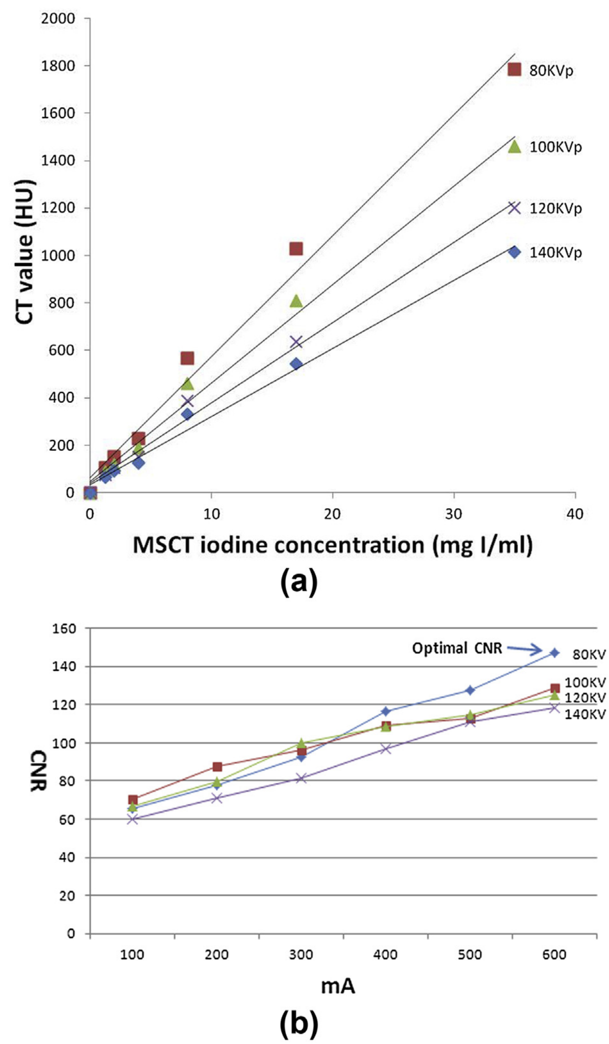


Figure 1 (a) Graph showing attenuation value as a representative of iodine concentration. The linear relationships for four tube voltage settings were as follows: at 80 kV, $y = 72.40 + 52.41x$ ($r = 0.985$); at 100 kV, $y = 57.54 + 42.71x$ ($r = 0.986$); at 120 kV, $y = 50.29 + 35.07x$ ($r = 0.986$); and at 140 kV $y = 45.04 + 29.84x$ ($r = 0.982$). (b) Corresponding CNRs from 80–140 kV and 100–600 mA, Optimal signal-to-noise ratio (8 mg iodine/ml) for 80 kVp, 600 mA.

Table 3
Quantitative image analysis.

Variable	Group A	Group B	p-Value[a]
Radiodensity (HU)			
Ascending aorta	350.2 ± 57.1	516.9 ± 66.9	<0.01
Internal carotid artery	362.5 ± 54.8	519.7 ± 69.4	<0.01
Vertebral artery	369.3 ± 56.5	517.8 ± 65.6	<0.01
Streak artefacts of venous	1044.2 ± 300.7	456.4 ± 157.2	<0.01
Sternocleidomastoid muscle	69.2 ± 1.7	71.0 ± 1.8	<0.01
Background noise	3.72 ± 0.14	3.76 ± 0.12	.21
Contrast-to-noise ratio	107.3 ± 21.2	162.2 ± 24.4	<0.01

Unless otherwise specified, data are means ± standard deviation.
[a] p-Value according to independent-samples t-test.

(Fig 1). Pearson's correlation coefficient (r) and the corresponding p-values were $r = 0.985$ and $p < 0.01$ at 80 kV, $r = 0.986$ and $p < 0.01$ at 100 kV, $r = 0.986$ and $p < 0.01$ at 120 kV and $r = 0.982$ and $p < 0.01$ at 140 kV. Attenuation at 80 kV (35 mg iodine/ml) was 18% higher than attenuation at 100 kV (35 mg iodine/ml), 33% higher than attenuation at 120 kV (35 mg iodine/ml) and 43% higher than attenuation at 140 kV (35 mg iodine/ml).

$CTDI_{VOL,}$ and CNR comparison

The phantom study found that the $CTDI_{VOL}$ was proportional to tube voltage and current. The tube (8 mg iodine/ml) with an iodine concentration in the blood vessels closest to human brain angiography was chosen as the standard for the CNR experiments. As there would be more noise, the lower tube current was set. When tube current reaches >500 mAs, the CNR of 80 kV will be higher than any other tube voltage. From Fig 1, it can be seen that 80 kV and 600 mAs produced the best CNR.

Clinical study: patient demographics

There were no significant differences between groups A and B with respect to age, weight, or height ($p > 0.05$, Table 1).

Radiation exposure

Statistics regarding radiation dose for the patients in the two groups are given in Table 2. The $CTDI_{vol}$ of group A and B was 31 and 14.4 mGy, respectively, which is a decline of 54%.

Table 4
Qualitative image analysis of the two groups.

Variable	Observers A			Observers B		
	Group A	Group B	p-Value	Group A	Group B	p-Value
Arterial enhancement	4.0 ± 0.9	4.8 ± 0.4	<0.01	4.1 ± 0.8	4.7 ± 0.4	<0.01
Streak artefacts of venous	3.0 ± 1.1	4.8 ± 0.3	<0.01	3.1 ± 0.9	4.8 ± 0.4	<0.01
Venous contamination	4.0 ± 0.7	4.0 ± 0.8	0.52	3.9 ± 0.8	4.0 ± 0.5	0.43
Image noise	4.2 ± 0.7	4.1 ± 0.7	0.77	4.1 ± 0.6	4.1 ± 0.5	0.62
All criteria	3.8 ± 1.0	4.5 ± 0.7	<0.01	3.8 ± 0.8	4.5 ± 0.5	<0.01

Unless otherwise specified, data are means ± standard deviation.
p-Value according to Mann–Whitney U-test.

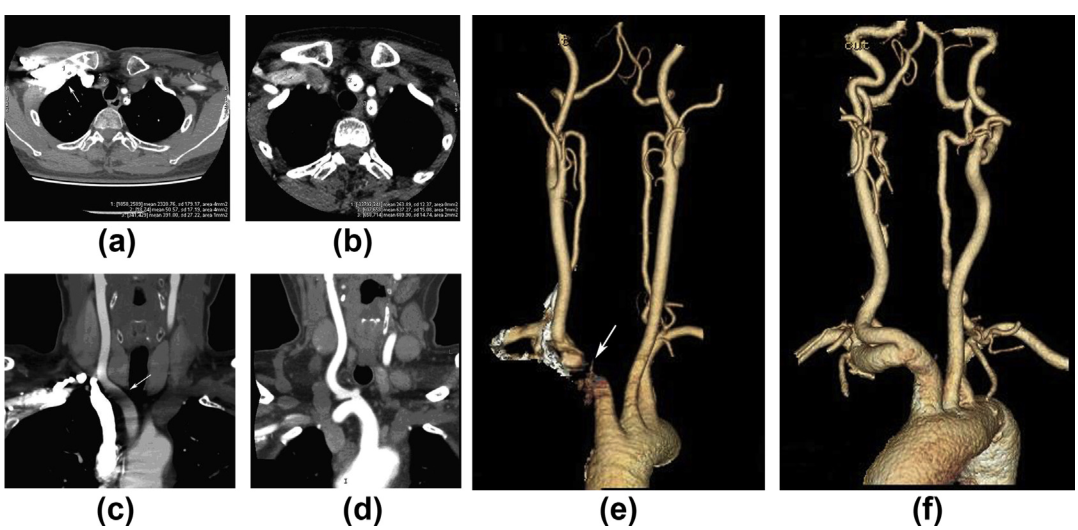
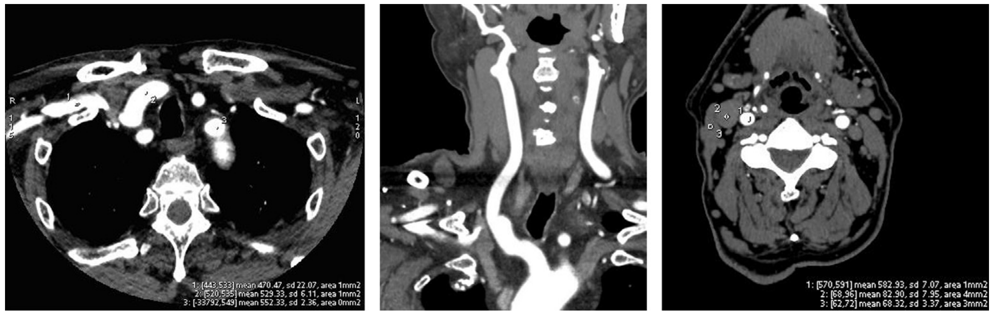


Figure 2 (a, c, e) CTA images of a 55-year-old woman using 370 mg iodine/kg contrast medium dose, 120 kV, and 400 mAs. (b, d, f) CTA images of a 62-year-old woman using 175 mg iodine/kg contrast medium dose, 80 kV, and 600 mAs. (a) Attenuation of peri-venous by streak artefacts reach 2320.76 HU. The attenuation of the innominate artery was only 50.57. (c, e) MPR and VR images of the innominate artery displayed poorly because of peripheral venous streak artefacts. (b) The attenuation of the right subclavian vein (264.89 HU) was much lower than that of the brachiocephalic trunk (637.27 HU), eliminating the venous streak artefacts. (d, f) MPR and VR images showing the innominate artery displayed perfectly.



(a) (b) (c)

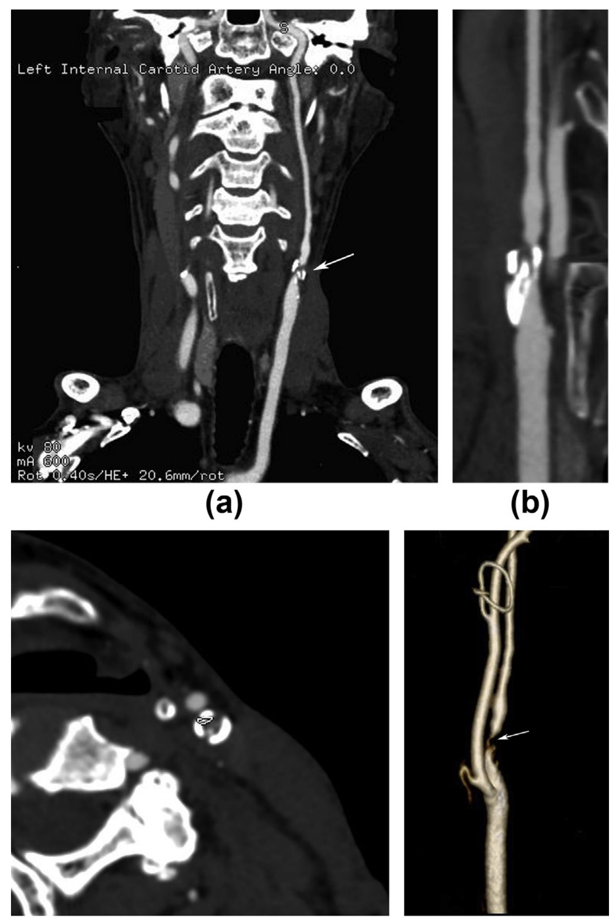
Figure 3 CTA in a 58-year-old man (weight 85 kg; the heaviest patient in this study), using a 40 ml contrast medium dose, 5 ml/s injecting speed, 80 kV, and 600 mAs. (a) Attenuation of the peripheral venous streak artefacts was 470.47 HU, lower than that of the innominate artery (529.23 HU). (b) Peripheral venous streak artefacts have no effect on the visualization of the right common carotid artery. (c) The attenuation values (582.93 HU, 517.87 HU) of the common carotid artery were good. The attenuation of the internal jugular vein was below 100 HU, and was little affected by venous streak artefacts, with a qualitative image score of 5.

Quantitative image analysis

The mean signal intensity for the ascending aorta, internal carotid artery, vertebral artery, and sternocleidomastoid muscle of group B were significantly higher than of group A (ascending aorta: 516.9 ± 66.9 versus 350.2 ± 57.1, $p < 0.01$; internal carotid artery: 519.7 ± 69.4 versus 362.5 ± 54.8, $p < 0.01$; vertebral artery: 517.8 ± 65.6 versus 369.3 ± 56.5, $p < 0.01$; sternocleidomastoid muscle: 71 ± 1.8 versus 69.2 ± 1.7, $p < 0.01$). However, the mean attenuation values for the venous streak artefacts of group B were significantly lower than for the group A protocol (456.4 ± 157.2 versus 1044.2 ± 300.7, $p < 0.01$). The CNR of group B was significantly higher than of group A (162.2 ± 24.4 versus 107.3 ± 21.2, $p < 0.01$,). The BN had no significant difference between group A and B (3.76 ± 0.12 versus 3.72 ± 0.14, $p = 0.21$, Table 3).

Qualitative image analysis

A comparison of axial images, MPR images, and VR images between groups A and B revealed no significant differences in terms of venous contamination and image noise. However, there were significantly higher differences for the group B protocol than for the group A protocol in the areas of arterial enhancement, venous streak artefacts, and all criteria (observer A, arterial enhancement: 4.8 ± 0.4 versus 4 ± 0.9, $p < 0.01$; venous streak artefacts: 4.8 ± 0.3 versus 3 ± 1.1, $p < 0.01$; all criteria: 4.5 ± 0.7 versus 3.8 ± 1, $p < 0.01$; observer B, arterial enhancement: 4.7 ± 0.4 versus 4.1 ± 0.8, $p < 0.01$; venous streak artefacts: 4.8 ± 0.3 versus 3.1 ± 0.9, $p < 0.01$; all criteria: 4.5 ± 0.5 versus 3.8 ± 0.8, $p < 0.01$; Table 4). Representative cases are shown in Figs 2 and 3.



(a) (b) (c) (d)

Figure 4 CTA images of a 65-year-old man using 175 mg iodine/kg contrast medium dose, 80 kV, and 600 mA. (a) MPR image showing mixed plaque of the left internal carotid artery. (b) Vascular image displays mixed plaque clearly, and shows severe left internal carotid artery stenosis. (c) Axial images distinctly show mixed plaque. (d) VR image displayed internal carotid artery stenosis. The degree of stenosis of the left side was approximately 90%.

Discussion

The present study revealed that the radiation dose could be significantly reduced by using a tube voltage of 80 kV for neck CTA. However, some early literature has shown that low tube voltage results in a direct photon-flow reduction, which has a direct effect on image noise and background noise, and might affect the diagnostic value of the images obtained because the depiction of structures was adversely affected when the tube voltage was lowered.[25] Two studies on the use of lower tube voltages for head CTA in a clinical setting had contradictory results. Ertl-Wagner et al.[26] found that higher tube voltage resulted in better image quality, whereas Bahner et al.[27] found that image quality benefited from lower tube voltage. As Ertl-Wagner et al. studied different tube voltages, all the tube currents were at 100 mAs. When the tube current is kept constant, the image noise will be significantly increased. Based on the findings of the present study, when the tube voltage is reduced to 80 kV, the attenuation of the iodinated contrast medium will be significantly increased (Fig 1a). As the tube current increased to >500 mAs, the noise of the 80 kV image decreased significantly (Fig 1b), where the CNRs were all higher than 100, 120, and 140 kV. The phantom study demonstrated that the parameters producing the best CNR were 80 kV and 600 mAs (Fig 2). In the clinical study, the CNR of group B increased by approximately 50% compared with A group. However, the radiation dose was reduced by 54% and image quality was obviously improved (Figs 4 and 5).

The contrast medium dosage of previous studies and the present authors' routine work was 40–80 ml.[28,29] However, some technical defects in the present authors' previous work were found: the images of 20% of the patients examined with traditional parameters indicated different degrees of venous streak artefacts (Fig 2). Some studies have reported work on the reduction of venous streak artefacts. Yoon et al.[22] used 80 ml contrast medium followed by a 40 ml saline flush and de Monyé et al.[23] suggested scanning in the craniocaudal direction. However, the effect was not marked. According to the present findings, the images of group B were of sufficiently high quality that venous streak artefacts could not be found. This mechanism was analysed as follows: the low-dose contrast medium (only 25–40 ml) decreased the contrast medium bolus time (6–8 s), which prolonged the interval time (8–10 s) between injection and scanning together with the time of intravenous saline flush dilution of the contrast medium. Only a small amount of contrast medium in the right subclavian vein remained. Conversely, for group A, the injection was larger (50–80 ml), the contrast medium bolus time (10–14 s) was prolonged, and accordingly, the interval time was shortened to 4–6 s, the contrast medium dilution by saline flush was insufficient, so venous streak artefacts were obviously produced by the high contrast medium concentration residues in the right subclavian vein. The study selected the right elbow median vein as the injection site for the following reasons: First, the more transverse course will be taken from the left brachiocephalic vein to the superior vena cava, which causes a higher possibility of undiluted contrast material obscuring the origins of the great vessels. Second, it is common in some patients, especially the elderly, that compression of the brachiocephalic vein by an ascending aorta can lead to contrast material pooling and subsequent reflux into the neck veins.

There are several limitations in the present study. First, patients >85 kg in weight were not included in the study. Recently, several studies have demonstrated that a tube voltage of 80 kV is not appropriate for larger-sized patients.[30] Second, scanning protocols cannot be compared intra-individually, as it is unethical to scan each patient with a combination of 120 kV, 400 mAs and 80 kV, 600 mAs.

In conclusion, the amount of contrast medium and the radiation dose decreased by 50% and 54%, respectively, when comparing group B (scan parameters: 80 kV, 600 mAs; 175 mg iodine/kg body weight contrast medium dose) with group A (scan parameters: 120 kV, 400 mAs;

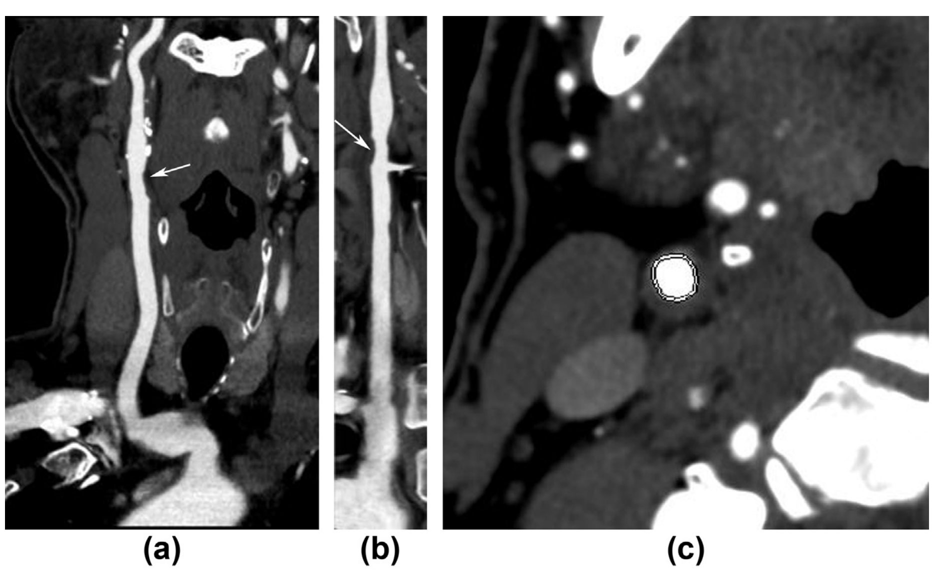


Figure 5 CTA images of a 58-year-old man using 175 mg iodine/kg, 80 kV, and 600 mA. (a) MPR image clearly displays the soft plaque in the right internal carotid artery. (b) Vascular image clearly shows the multi-soft plaque in the right common carotid artery. (c) Axial image clearly displays the soft plaque of the right internal carotid artery.

350 mg iodine/kg body weight contrast medium dose). Moreover, the CNR increased by 50% and venous streak artefacts were eliminated compared with the conventional protocol. Therefore, when conducting CTA of the neck using 64-detector row spiral CT, a tube voltage of 80 kV, a current of 600 mAs, a contrast medium concentration of 175 mg iodine/kg body weight, and 50 ml saline flush are recommended.

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