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Cerebral CT angiography with iterative reconstruction at 70 kVp and 30 mL iodinated contrast agent: Initial experience

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ABSTRACT

Objectives: To evaluate the radiation dose and image quality of cerebral CT angiography (CTA) at 70 kVp with 30 mL iodinated contrast agent.

Methods: One hundred patients were prospectively classified into two groups: Group A ($n = 50$), 120 kVp cerebral CTA with 60 mL iodinated contrast agent reconstructed by filtered back projection (FBP) and Group B ($n = 50$), 70 kVp with 30 mL iodinated contrast agent reconstructed by sinogram-affirmed iterative reconstruction (SAFIRE). CT values, noise, signal-to-noise ratio (SNR) and contrast-to-noise ratio (CNR) of the internal carotid artery (ICA) and middle cerebral artery (MCA) were measured. Subjective image quality was evaluated. Effective dose (ED) was calculated.

Results: The mean CT values of the ICA and MCA of Group B were higher than those of Group A (all $P < 0.001$). The mean noise of Group A was lower than that of Group B ($P < 0.001$). SNR_{ICA}, SNR_{MCA} and CNR_{ICA}, CNR_{MCA} of Group A were higher than Group B (all $P < 0.001$). There was no difference in vessel sharpness, noise, and overall quality between the two groups (all $P > 0.05$). ED of Group B (0.2 ± 0.0 mSv) was lower than Group A (1.3 ± 0.1 mSv) ($p < 0.001$).

Conclusion: Cerebral CTA with iterative reconstruction at 70 kVp and 30 mL iodinated contrast agent is feasible, allowing for substantial dose reduction compared with conventional cerebral CTA protocol.

1. Introduction

Intracranial aneurysm rupture is the most common cause of subarachnoid hemorrhage, it is estimated that 30% of survivors have moderate to severe disability [1–3]. Digital subtraction angiography (DSA) remains the gold standard for evaluating intracranial aneurysms; however, it may cause several severe neurologic complications due to its invasive nature [4]. Nowadays, cerebral CT angiography (CTA) has been an important non-invasive modality for diagnosis of intracranial aneurysms, especially in the case of subarachnoid hemorrhage, because of its high sensitivity and specificity [5–10]. However, the wide application of cerebral CTA has been restricted by some inherent drawbacks, such as relatively high radiation dose and a considerable volume of iodinated contrast agent. Therefore, the issue of reducing radiation dose and the amount of iodinated contrast agent has been widely concerned in the premise of diagnostic image quality.

More recent developments in CT technology have reduced radiation dose and contrast agent amount. Several radiation dose saving strategies, such as low tube voltage technique, low tube current and iterative reconstruction (IR) algorithms, have been applied separately or jointly to decrease the radiation dose of cerebral CTA [11–14]. Of above-mentioned radiation dose saving techniques, low tube voltage technique is the mainstay of low radiation dose CTA. Moreover, iodinated contrast agent has a higher CT attenuation at low photon energy, it is therefore potential to simultaneously reduce the radiation dose and the volume of iodinated contrast agent by lowering tube voltage. However, high noise is always observed in low radiation dose and low contrast agent volume CTA images reconstructed with filtered back projection (FBP) algorithm, a currently common algorithm with high reconstruction speed and relatively acceptable image quality in most cases [15], thus, reduced image quality was often complained. Sinogram-affirmed iterative reconstruction (SAFIRE) is a hybrid algorithm based on raw-data domains and image domains, which can improve vessel wall delineation and reduce image noise compared with FBP,

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Abbreviations: CNR, contrast-to-noise ratio; CTA, CT angiography; CTDIvol, volume CT dose index; DLP, dose length product; ED, Effective dose; FBP, filtered back projection; ICA, internal carotid artery; IR, iterative reconstruction; MCA, middle cerebral artery; SAFIRE, sinogram-affirmed iterative reconstruction; SNR, signal-to-noise ratio.

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especially in low radiation dose CTA protocol [16–19]. However, the application of iterative reconstruction requires powerful computational capacity due to its mathematically demanding properties and the large amount of data in CT imaging [20], Moreover, CT images may appear paint-brushed with higher levels of SAFIRE [21], thus, the highest level of SAFIRE has not recommended in clinical practice. Luo et al. [14] reported that 100 kVp or 80 kVp cerebral CTA using 30 mL contrast agent can maintain the diagnostic accuracy for detecting intracranial aneurysms. Chen et al. [13] reported that 70 kVp cerebral CTA with SAFIRE and 60 mL contrast agent can obtain diagnostic image quality with 85% effective dose reduction compared with 120 kVp CTA protocol. It appears that it should have enough space to further reduce contrast agent load for cerebral CTA at 70 kVp. Therefore, the purpose of this study was to evaluate the feasibility of cerebral CTA at 70 kVp combined with SAFIRE and 30 mL iodined contrast agent volume

2. Material and methods

2.1. Patients

This prospective study was performed with institutional review board approval. Informed consent was obtained from all patients or their legal guardians. One hundred and twenty-three consecutive patients with suspected subarachnoid hemorrhage, intracranial aneurysm or cerebrovascular disease were enrolled in this study between May 2014 and January 2015. Contraindications for cerebral CTA included known allergic reactions to iodinated contrast agent, severe renal impairment, pregnancy, and lactation period. Patients with moyamoya disease, motion artifacts, internal carotid artery (ICA) and/or middle cerebral artery (MCA) occlusion, or intracranial clipping or coiling were excluded from the study. These exclusion factors may impede the attenuation measurements of ICA and/or MCA. Each patient's body weight and height were measured and recorded prior to the CT examination.

2.2. Cerebral CT angiography

2.2.1. Acquisition protocol

All cerebral CTA examinations were performed on a dual-source CT system (Somatom Definition Flash, Siemens Healthcare, Forchheim, Germany). The patients were randomly assigned into two groups according to CT tube voltage and iodinated contrast agent volume. In Group A, the patients were examined at 120 kVp and 60 mL iodinated contrast agent. In Group B, the patients were scanned at 70 kVp and 30 mL iodinated contrast agent. Image acquisition parameters included a collimation of 64 × 2 × 0.6 mm, rotation time of 0.5 s, and a pitch of 1.2. Automatic tube current modulation (Care dose 4D) was used in each patient for both CTA protocols.

In group A, 60 mL of iodinated contrast agent (iopromide, Ultravist 300 mg I/mL, Bayer Schering Pharma, Berlin, Germany) was intravenously injected with a flow rate of 4.0 mL/s, while in group B, 30 mL of iodinated contrast agent (iopromide, Ultravist 300 mg I/mL, Bayer Schering Pharma, Berlin, Germany) was intravenously injected with a flow rate of 4.0 mL/s, then 30 mL of saline solution was injected for each patient in both groups. CT acquisition was triggered by using a bolus tracking technique with the region of interest (ROI) placed in the right internal carotid artery (ICA) at 120 kVp. Image acquisition was started 3 s after the attenuation reached the predefined threshold of 100 HU. The acquisition time was approximately 3–4 s.

2.3. Image reconstruction

CT images in Group A were reconstructed with the conventional FBP algorithm, while CT images in Group B were reconstructed at 4th level of SAFIRE (S4). All image series were reconstructed with a 0.75 mm section thickness and 0.5 mm increment. The convolution kernels of groups A and B were J30f and H30f, respectively. Each image dataset was coded, patient information was removed, and the sets were randomized to enable double-blinded evaluation.

2.4. Image quality evaluation

2.4.1. Objective image quality evaluation

All images were transferred to a dedicated workstation (Multi Modality Workplace; Siemens Healthcare). All measurements were performed by one neuroradiologist (xx with 6 years experience in reading). The CT value was measured by placing a circular ROI in the center of the ICA (Fig. 1**A**) and MCA on both sides on thin-slice axial CT images (Fig. 1**B**). The area of ROI was 0.15–0.2 cm^2 for ICA and 0.03–0.06 cm^2 for MCA, respectively. To avoid partial volume effects, ROIs were placed in the cavernous segment of the ICA and the first segment of the MCA [14]. The ROI was drawn within the target vessel without including the lumen walls, calcifications, or thrombosis. Measurements were performed three times and the average values were calculated. CT values of the left and right ICA/MCA were averaged for each patient, and were regarded as the final data for statistical analysis. CT values of the brain parenchyma were obtained by placing a ROI with an approximate area of 1 cm^2 in the white matter at the level of the centrum semiovale while avoiding vascular structures. Image noise was defined as the standard deviation (SD) of the CT value in the brain parenchyma. Signal-to-noise ratio (SNR) and contrast-to-noise ratio (CNR) were calculated using the following equations [12,22]:

$$\mathrm{SNR}_a = \mathrm{CTvalue}_a/\mathrm{SD} \quad (1)$$

$$\mathrm{CNR}_a = (\mathrm{CTvalue}_a - \mathrm{CTvalue}_b)/\mathrm{SD} \quad (2)$$

Where CT value_a is the mean HU of the target artery, CT value_b is the mean HU of brain parenchyma, and SD is the standard deviation of the CT value in the brain parenchyma.

2.5. Subjective image quality evaluation

Image quality was rated in multiplanar reconstructions, maximum intensity projections and volume-rendered reformatted images. Qualitative image scoring of CTA datasets was performed independently by two neuroradiologists (xx and xx with 6 and 4 years of reading experience). Both neuroradiologists were blinded to the tube voltage, contrast agent volume and reconstruction method. In the case of disagreement between both readers, consensus was reached in a joint reading to determine the final image quality score. The image quality of CTA was rated on a four-point scale [13,23–25]. Both readers were instructed to evaluate the images according to the degree of vessel sharpness, noise and overall quality. Vessel sharpness was graded as follows: 1, blurry; 2, suboptimal; 3, good; 4, sharpest. Image noise was graded as follows: 1, noisy, degrades image so that no evaluation possible 2, noisy, but permits evaluation; 3, low; 4, little to no noise; Overall quality was graded combined with the effect of calcified plaques as follows: 1, non-diagnostic, severe artefacts so that no diagnostic interpretation; 2, acceptable, moderate artefacts but images still interpretable; 3, good, slight artefacts; 4, excellent, no significant artefacts, as shown in Fig. 2.