Craniocervical computed tomography angiography with adaptive iterative dose reduction 3D algorithm and automatic tube current modulation in patients with different body mass indexes

Shujing Yu, BS*, Jing Zheng, MD, Li Zhang, MD

Abstract
The aim of this study was to investigate the feasibility of head and neck computed tomography angiography (CTA) using the 80-kV tube voltage and the adaptive iterative dose reduction (AIDR) 3D algorithm in patients with different body mass indexes (BMIs).

From November 2016 to January 2017, 128 consecutive patients scheduled for head and neck CTA examinations were randomized into the 100-kV group (n=60) and the 80-kV group (n=68). Both groups used the automatic tube current modulation technique and the AIDR 3D algorithm. The patients were further grouped as slender (BMI < 22 kg/m²), normal weight (BMI 22–25 kg/m²), and overweight (BMI ≥ 25 kg/m²). The image quality and the radiation dose of each subgroup were analyzed.

The images of the head and neck vessels and the brain tissue obtained with 100 kV were all of diagnostic quality. Slender and normal weight patients imaged with 80 kV also produced images of diagnostic quality. However, 80 kV in the overweight patients failed to produce images of diagnostic quality. The radiation dose in the patients imaged with 80 kV was significantly decreased in comparison with those imaged with 100 kV. The effective dose was 0.36 ± 0.06 and 0.41 ± 0.05 mSv in the slender and normal weight patients imaged with 80 kV.

Head and neck CTA scanning with 80 kV, automatic tube current modulation, and AIDR 3D algorithm can produce high quality images with reduced radiation dose in slender or normal weight patients.

Abbreviations: AIDR = adaptive iterative dose reduction, BMIs = body mass indexes, CNR = contrast-to-noise ratio, CTA = computed tomography angiography, CTDI = CT dose index, DLP = dose-length product, FBP = filtered back projection.

Keywords: body mass index, computed tomography, iterative reconstruction, radiation dose

1. Introduction
Computed tomography angiography (CTA) is the first choice for diagnosing head and neck vascular diseases due to its non-invasiveness. However, it has been a concern that CTA may affect the lens and thyroid, which are sensitive to radiation. In addition, computed tomography (CT) examination has been associated with an increased risk of cancer. Great endeavors have been taken to reduce the diagnostic radiation doses, including novel image reconstruction algorithms.

CT scans using the iterative reconstruction algorithm have superior image quality and lower radiation doses in comparison with the filtered back projection (FBP) algorithm. The adaptive iterative dose reduction (AIDR) 3D algorithm, which is based on the raw data space and the image space, can minimize radiation dose by reducing tube voltage or current, without compromising image quality. It has been shown that the AIDR 3D algorithm is associated with high spatial resolution, less noise, and excellent images. In head and neck CTA examinations, the scanning protocol of 80 kV plus AIDR 3D significantly increased vascular attenuation and contrast-to-noise ratio (CNR) in comparison with 120 kV plus FBP. Another study showed that CTA with 100 kV plus AIDR 3D significantly reduced radiation dose by 71%.

It has been shown that coronary CTA with lower tube voltage had reduced radiation dose in patients with normal body mass index (BMI). Another study found that radiation dose was positively correlated with BMI in craniocervical CTA. We speculate that BMI may be a factor for consideration in planning head and neck CTA protocols with lower radiation doses. Therefore, our present study aimed to compare CTA scans of 100 kV plus AIDR 3D with those of 80 kV plus AIDR 3D among patients with different BMIs.

2. Materials and methods
2.1. Patients
Our study was approved by the ethics committee of Cangzhou Central Hospital. Informed consent was obtained from all patients before the enrollment. Informed consent was obtained from all patients before the enrollment.
patients before the enrollment. From November 2016 to January 2017, 128 consecutive patients scheduled for head and neck CTA examinations were prospectively enrolled in our study. Their primary symptoms include headache, dizziness, and numbness of the limbs. All the patients had no previous history of allergy to iodine or major organ insufficiency. The patients were randomized into the 100-kV group (n = 60) and the 80-kV group (n = 68). The patients were further grouped as slender (BMI < 22 kg/m²), normal weight (22 kg/m² ≤ BMI < 25 kg/m²), and overweight (BMI ≥ 25 kg/m²).

2.2. Scanning protocols
All CTA examinations were performed with an 80-row CT scanner (PRIME, Toshiba, Japan). The following scanning settings were used: collimator 80 × 0.5 mm, pitch 0.831:1, slice thickness 0.5 mm, slice gap 0.5 mm, gantry rotational speed 0.5 s/ r, field of view 320 × 320 mm, and matrix size 512 × 512. Both groups used the automatic tube current modulation technique (40–600 mA), a noise index of 15.0, and the AIDR 3D algorithm. The scanning covered the length from the aortic arch to the cranial base with ancaudal-to-rostral direction. The scanning was triggered by the automatic bolus tracking technique. The region of interest (ROI) included the descending aorta at the level of the aortic arch, with a triggering threshold of 160 HU. Iohexol 350 (60 mL, 320 mg iodine/1 mL) was infused at 4 mL/s, followed by a bolus injection of 40 mL normal saline infused at 4 mL/s. The acquired raw data were transferred to a Vitrea Fx workstation for image analysis and reconstruction.

2.3. Objective assessment of image quality
The attenuation and the standard deviation were measured in the axial images of 0.5 mm slice thickness for the following structures: the right common carotid artery and the sternoclavomastoid at the C7 level, the right carotid sinus and the sternoclavomastoid at the C4 level, the right internal carotid artery and the masseter at the C1 level, and the M1 segment of the right middle cerebral artery and the brain tissue. The arterial ROI was placed in the center of the vessel, occupying approximately 2/3 of the lumen. The plaques were avoided. The ROIs for the muscular tissues and the brain tissues were set as 45 mm², avoiding the artifacts. Upon arterial stenosis or occlusion, the contralateral artery or muscular/brain tissue was measured instead. The signal-to-noise ratio (SNR) and the CNR were calculated using the formula: effective dose = DLP / K. The K value was 0.0031 according to the European guidelines on quality criteria for CT.[14]

2.4. Subjective assessment of image quality
Two radiologists with over 5 years of experience in head and neck CTA reviewed the CT images. They were blind to the scanning protocols and the study design, but not to the patient information. The image quality was assessed using the axial images of 0.5-mm slice thickness and curved planar reformation/maximal intensity projection (CPR/MIP) images. The cerebral arteries were assessed for the segments of level 3 and above.

The vascular image quality was categorized as 1 of the 5 scores from 1 to 3: 5 points, the vessels were fully filled with uniform intravascular density and sharp vascular wall, no artifacts; 4 points, the vessels were fully filled with uniform intravascular density, slightly blurred vascular wall or mild artifacts; 3 points, the vessels were generally well filled with uneven intravascular density, slightly blurred vascular wall or mild artifacts, but the images were still assessable; 2 points; the vessels were poorly filled with uneven intravascular density, blurred vascular wall, and significant artifacts, and the assessment was limited; 1 point, the vessels were not recognizable with significant artifacts, and the diagnosis was not possible. Images with a score ≥ 3 were deemed of diagnostic quality, while those with a score ≤ 2 were deemed of non-diagnostic quality.

The quality of the brain tissue images was also categorized as 1 of the 5 scores from 1 to 5: 5 points, the subarachnoid space was clear with well demarcated gray/white matter, fine image particles, no artifacts; 4 points, the subarachnoid space and the gray/white matter demarcation were recognizable, and the image particles were evenly distributed but not fine, no significant artifacts; 3 points, the subarachnoid space and the gray/white matter demarcation were barely recognizable, and the image particles were unevenly distributed with mild artifacts; 2 points, the subarachnoid space and the gray/white matter demarcation were barely recognizable, and the image particles were slightly blurred with coarse particles; 1 point, the images were blurred with very coarse particles. Images with a score ≥ 3 were deemed of diagnostic quality, while those with a score ≤ 2 were deemed of non-diagnostic quality.

2.5. Radiation dose assessment
The dose-length product (DLP) and the CT dose index (CTDI) were obtained from the CT scanner. The effective dose was calculated using the formula: effective dose = DLP × K. The K value was 0.0031 according to the European guidelines on quality criteria for CT.[14]

2.6. Statistical analysis
The continuous data were compared using the Student’s t-test. The categorical data were compared using the chi-square test. The subjective scores of image quality were compared using the Mann–Whitney test. The interrater agreement was analyzed using the intraclass correlation coefficient. All statistical analyses were performed using the SPSS 19.0 software. P < .05 was considered statistically significant.

3. Results
There was no significant difference in gender, age, and BMI between the sub-BMI groups (all P > .05, Table 1).

3.1. Image quality
The 3 sub-BMI groups imaged with 80kV had significantly higher attenuation, noise, SNR, and CNR of the neck vessels in comparison with those imaged with 100kV (all P < .05). Whereas in terms of the head vessels, the 3 sub-BMI groups imaged with 80kV had significantly higher attenuation and noise, but not SNR or CNR, in comparison with those imaged with 100kV (all P < .05, Table 2).
3.2. Radiation dose

The CTDI in the slender, normal weight and overweight patients imaged with 80 kV was significantly decreased by 15.17%, 18.29%, and 22.71%, respectively, in comparison with their corresponding sub-BMI groups imaged with 100 kV (all < .05). Similarly, The DLP in the slender, normal weight and overweight patients imaged with 80 kV was significantly decreased by 15.42%, 20.61, and 21.71%, respectively, in comparison with their corresponding sub-BMI groups imaged with 100 kV (all < .05). The effective dose was 0.36 ± 0.06, 0.41 ± 0.03, and 0.50 ± 0.06 mSv in the slender, normal weight, and overweight patients imaged with 80 kV (Table 4).

3.3. Interrater agreement

There was no significant difference in the intraclass correlation coefficient between the 2 radiologists (P > .05).

### Table 2

Comparison of the attenuation, SNR, and CNR of the vessels.

|                      | Slender (BMI < 22 kg/m²) | Normal weight (22 kg/m² < BMI < 25 kg/m²) | Overweight (BMI > 25 kg/m²) |
|----------------------|--------------------------|------------------------------------------|-----------------------------|
|                      | Neck                     | Head                                     | Neck                        | Head                        | Neck                        | Head                        |
| **Attenuation (HU)** |                          |                                          |                             |                             |                             |                             |
| 100 kV               | 531.32 ± 49.24           | 485.12 ± 58.22                          | 486.02 ± 80.04              | 449.37 ± 60.45              | 469.87 ± 66.25              | 444.59 ± 62.06              |
| 80 kV                | 729.27 ± 122.90          | 677.78 ± 96.73                          | 651.13 ± 149.05            | 612.57 ± 144.68            | 643.69 ± 132.06            | 593.78 ± 119.36            |
| t                    | −5.509                   | −7.042                                   | −4.657                      | −4.868                      | −5.198                      | −5.287                      |
| P                    | < .0001                  | < .0001                                  | < .0001                     | < .0001                     | < .0001                     | < .0001                     |
| **Noise**            |                          |                                          |                             |                             |                             |                             |
| 100 kV               | 14.82 ± 2.01             | 19.75 ± 5.44                             | 14.84 ± 1.42                | 19.62 ± 3.01                | 15.35 ± 2.16                | 17.82 ± 2.99                |
| 80 kV                | 17.16 ± 0.91             | 23.64 ± 2.61                             | 17.24 ± 1.57                | 22.73 ± 2.87                | 18.34 ± 1.90                | 21.95 ± 2.90                |
| t                    | −4.463                   | −3.447                                   | −5.888                      | −5.550                      | −4.828                      | −4.570                      |
| P                    | < .0001                  | < .0001                                  | < .0001                     | < .0001                     | < .0001                     | < .0001                     |
| **SNR**              |                          |                                          |                             |                             |                             |                             |
| 100 kV               | 36.37 ± 5.17             | 25.42 ± 6.09                             | 32.92 ± 5.54                | 23.18 ± 3.69                | 30.90 ± 5.33                | 25.42 ± 4.30                |
| 80 kV                | 42.65 ± 8.09             | 28.80 ± 6.37                             | 37.90 ± 8.69                | 27.13 ± 6.07                | 35.19 ± 6.67                | 27.57 ± 5.89                |
| t                    | −2.684                   | −1.783                                   | −2.303                      | −2.622                      | −2.279                      | −1.331                      |
| P                    | .012                     | .085                                     | .027                        | .012                        | .028                        | .191                        |
| **CNR**              |                          |                                          |                             |                             |                             |                             |
| 100 kV               | 32.00 ± 4.68             | 23.28 ± 5.60                             | 28.67 ± 5.58                | 21.13 ± 3.47                | 26.70 ± 5.20                | 23.10 ± 4.02                |
| 80 kV                | 38.72 ± 7.89             | 27.09 ± 3.50                             | 33.98 ± 8.80                | 25.27 ± 5.95                | 31.51 ± 6.77                | 25.62 ± 5.79                |
| t                    | −3.026                   | −2.173                                   | −2.431                      | −2.834                      | −2.552                      | −1.615                      |
| P                    | .005                     | .038                                     | .020                        | .007                        | .015                        | .114                        |

BMI = body mass index. CNR = contrast-to-noise ratio. SNR = signal-to-noise ratio.
Table 3
Subjective scores of the image quality.

|                          | 100-kV group (n=60) | 80-kV group (n=68) | P-value |
|--------------------------|----------------------|---------------------|---------|
| **Slender (BMI<22kg/m²)** |                      |                     |         |
| Right internal carotid artery at the C1 level | 4.90 ± 0.27          | 4.77 ± 0.33         | .305    |
| Right carotid sinus at the C4 level          | 5.00 ± 0.00          | 5.00 ± 0.00         | 1.000   |
| Right common carotid artery at the C7 level  | 4.63 ± 0.47          | 4.46 ± 0.48         | .287    |
| Right middle cerebral artery                 | 4.66 ± 0.41          | 4.77 ± 0.39         | .404    |
| Brain tissue                                | 3.68 ± 0.38          | 3.31 ± 0.25         | .008    |
| **Normal weight (22 kg/m²≤BMI<25 kg/m²)**    |                      |                     |         |
| Right internal carotid artery at the C1 level | 4.77 ± 0.37          | 4.59 ± 0.39         | .064    |
| Right carotid sinus at the C4 level          | 5.00 ± 0.00          | 4.91 ± 0.25         | .083    |
| Right common carotid artery at the C7 level  | 4.55 ± 0.46          | 4.15 ± 0.53         | .014    |
| Right middle cerebral artery                 | 4.36 ± 0.56          | 4.50 ± 0.66         | .258    |
| Brain tissue                                | 3.52 ± 0.36          | 3.02 ± 0.35         | .000    |
| **Overweight (BMI≥25 kg/m²)**                |                      |                     |         |
| Right internal carotid artery at the C1 level | 4.74 ± 0.42          | 4.56 ± 0.40         | .118    |
| Right carotid sinus at the C4 level          | 4.95 ± 0.16          | 4.92 ± 0.19         | .568    |
| Right common carotid artery at the C7 level  | 4.34 ± 0.55          | 3.88 ± 0.56         | .012    |
| Right middle cerebral artery                 | 4.32 ± 0.45          | 4.40 ± 0.59         | .429    |
| Brain tissue                                | 3.40 ± 0.52          | 2.92 ± 0.32         | .002    |

BMI = body mass index.
4. Discussion

Our study showed that the images of the head and neck vessels or brain tissues in the sub-BMI patients imaged with 100 kV were of diagnostic quality. The slender and normal weight patients imaged with 80 kV also produced vascular and brain tissue images of diagnostic quality. However, only the head and neck vascular images were of diagnostic quality in the overweight patients imaged with 80 kV. These results suggested that BMI may affect the image quality during CTA scanning with 80 kV.

It has been shown that head and neck CTA scanning performed with 80 kV and AIDR 3D algorithm had significantly higher vascular attenuation and CNR and lower radiation doses in comparison with that performed with 120 kV and FBP algorithm,[9,10] However, these studies did not examine the brain tissue. Our findings confirmed the effectiveness of 80 kV and AIDR 3D in reducing CTA radiation doses in both vessels and brain tissues. The reduced tube voltage enhanced the contrast between the vessels and the adjacent structures, which resulted in higher vascular attenuation, noise, SNR, and CNR. This inhibited the effects of image noise and produced vascular images of high quality. However, the noise was not adequately inhibited due to the small disparity in brain tissue attenuation, despite the use of the AIDR 3D algorithm.

Yu et al showed that head and neck CTA with 100 kV plus AIDR 3D significantly reduced the radiation dose by 71% without compromising the image quality.[11] Inconsistent with the results of Yu et al,[11] our study showed that CTA scanning with 80 kV (plus automatic tube current modulation and AIDR 3D algorithm) in the slender and normal weight patients can produce vascular images of high quality, in addition with the ability to assessing the brain tissue. The radiation dose in the patients imaged with 80 kV was significantly decreased in comparison with those imaged with 100 kV. The effective dose was 0.36±0.06 and 0.41±0.05 mSv in the slender and normal weight patients imaged with 80 kV.

In our study, the minimum vascular attenuation was near 600 HU, which is far beyond the optimal attenuation range for diagnosis (250–300 HU).[15] Excessively high attenuation can result in beam hardening artifact, which may compromise the accuracy in evaluating vascular plaques and stenosis. The high attenuation may be reduced by using a contrast of low concentration and a slower infusion rate.

In conclusion, head and neck CTA scan with 80 kV tube voltage, automatic tube current modulation, and AIDR 3D algorithm is recommended for patients with a BMI less than 25. This scanning protocol can produce vascular and brain tissue images of high quality, as well as lower radiation dose for better patient safety.

Author contributions

Conceptualization: Li Zhang.
Data curation: Jing Zheng.
Formal analysis: Li Zhang.
Methodology: Jing Zheng, Li Zhang.
Resources: Jing Zheng, Li Zhang.
Supervision: Li Zhang.
Validation: Shujing Yu, Jing Zheng.
Writing – original draft: Shujing Yu.
Writing – review & editing: Shujing Yu.

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