Low-dose CT angiography of the supraaortic arteries: image quality and radiation exposure at 80kV tube voltage settings

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Purpose

Computed tomography angiography (CTA) of the supraaortic vessels has shown to be a powerful tool providing high diagnostic accuracy. However, there are disadvantages including the use of iodinated contrast agents and radiation exposure including the region of the thyroid gland (1). Reduction of radiation dose therefore has become a very important issue in modern computed tomography (CT) imaging, as CT has evolved to one of the most important cause for human radiation exposure (2).

The use of low tube voltage is a very powerful way of reducing radiation dose in CTA. It is leading towards a lower photon energy which results in higher attenuation levels of iodinated contrast agents (3, 4). With the advantage of low radiation dose, this effect might even influence the quality of CTA examinations at low tube voltage positively as vascular enhancement increases.

The aim of our present study was to assess if the radiation dose can be substantial decreased at CTA of the supraaortic arteries by lowering the kV settings without relevant loss in diagnostic image quality, using a 64 slice computed tomography scanner.
Fig. 0: VRT image of the carotid arteries at 120 kV (ED = 3.93 mSv)

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Methods and Materials

Materials and Methods:

42 patients (16 female, 26 male; age range 39-90; mean age 65.3y) with suspected vascular disease of the supraaortic arteries were included in this prospective, randomized study. Exclusion criteria were defined by renal insufficiency, known allergic reaction against ionated contrast media, age < 18, pregnancy, and breast feeding.

Computed tomography angiography image acquisition:

Examinations were carried out using a 64-row multi-slice CT scanner (Philips Medical Systems, The Netherlands). Iopamidole, a non-ionic iodinated contrast medium, was used at a concentration of 400mg iodine/ml for all CT studies in both groups (Iomeron 400, Bracco Austria).

A Care Bolus technique was used with the reference scan at the level of the descending aortic artery and an automatic start of the scan 5 seconds after achieving a threshold of 150 HU within this region. We applied a monophasic contrast injection protocol, consisting of an injection of 70ml of contrast injected at a flow rate of 5 ml/s, followed by a saline flush of 40.

CTA was performed in caudocranial direction from the aortic arch to the calvarium with a detector configuration of 64’0.625 mm, combined with a table increment of 0.45 mm (= 9 mm/second). Tube voltage settings were 120kV in group A and 80kV in group B. All other acquisition parameters including the fixed tube current (300 mAs) were kept constant (Figure 1).

Evaluation: Signal-to-noise and Contrast-to-noise ratio

Signal intensity measurements for the calculation of the contrast-to-noise ratio (CNR) and signal-to-noise ratio (SNR) were performed bilaterally at three different levels, using axial images. Measurements were performed within the common carotid artery, the carotid bifurcation and within the internal carotid artery. SI intensities for CNR and SNR calculation were obtained from the sternocleidomastoid muscle (at the same level of the vessels measurements), background noise was obtained from three areas of the surrounding air.

CNR and SNR were calculated according to the following formulas:
CNR = (SIves - SIsterno)/SD BN;

SNR = (SIves/ SD BN)

(SIves = Signal intensity within the vessel, SIsterno = Signal intensity within the sternocleidomastoid muscle, SD BN = average standard deviation of the surrounding air at right, left and anterior position).

**Evaluation: Image quality**

Subjective image quality was evaluated by two readers, using a 4 point scale (0= nondiagnostic, 1 = diagnostic, but poor quality, 2 = good quality, 3 = excellent). For this evaluation the vascular tree was subdivided in 7 segments on each side that had to be evaluated; 1) the common carotid artery, 2) the carotid artery at the level of the bifurcation, 3) the internal carotid artery in its extracranial course, 4) the internal carotid artery in its intracranial course, 5) the V1 segment, 6) the V2/3 segment and 7) the V4 segment.

Image quality was analyzed in a separate session by two experienced radiologists blinded to the CT-protocol used as the images were read in an anonymized fashion.

**Evaluation: Radiation Dose**

For the evaluation of radiation dose, the Dose-Length-Product (DLP) and the Effective Dose (ED) was compared between the two study groups. ED was calculated by multiplying the DLP with a standard conversion factor for the head and neck region (0,0054 mSv mGy\(^{-1}\) cm\(^{-1}\))

**Statistical analysis:**

Metric data like BMI or HU were expressed using means ± standard deviations. Nominal data are presented using percentages. Unpaired t-tests were used for metric data to assess differences between 80 and 120 kV.

For the assessment of subjective image quality the subjective image score was divided into two groups whereas 0 and 1 was considered to be poor image quality and 2 and 3 was considered to be good image quality suitable for diagnostic routine. For this nominal data, comparisons between group A, B crosstabs and chi\(^2\) tests were used. In order to avoid an increasing error of the second type no multiplicity corrections were performed.
**Fig. 0:** Patient characteristics and scanning details:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Group A (120 kV)</th>
<th>Group B (80 kV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex (female/male)</td>
<td>9female/12male</td>
<td>7female/14male</td>
</tr>
<tr>
<td>Age (years)</td>
<td>66,5±12 (43-86)</td>
<td>64,1±11,8 (39-90)</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>27,3±4,1 (20,7-36,2)</td>
<td>27,1±2,8 (22,1-33,5)</td>
</tr>
<tr>
<td>Scan Range (cm)</td>
<td>42±3,5 (35,8-48,5)</td>
<td>42,1±2,9 (37,4-48,6)</td>
</tr>
<tr>
<td>Kilovoltage (kV)</td>
<td>120 kV</td>
<td>80 kV</td>
</tr>
<tr>
<td>Tube current (mAs)</td>
<td>300mAs</td>
<td>300mAs</td>
</tr>
<tr>
<td>Nominal CDTI</td>
<td>17,3 mGy</td>
<td>5,4 mGy</td>
</tr>
<tr>
<td>Slice Collimation (mm)</td>
<td>64x0.625 mm</td>
<td>64x0.625 mm</td>
</tr>
<tr>
<td>Table feed / rotation (mm)</td>
<td>9mm</td>
<td>9mm</td>
</tr>
</tbody>
</table>

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**Fig. 0:** VRT image of the carotid arteries at 120 kV (ED = 3.93 mSv)

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**Fig. 0:** VRT image of a CTA at 80 kV in a patient with an stenotic and occluded right internal carotid artery demonstrating good image quality at an ED of only 1.23 mSv.

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Results

**Patient population:**

Patients characteristics like height, weight and body mass index as potential influencing factor for image quality in CT examinations showed no significant differences between the groups.

**Technical success:**

Technical success was achieved in 41 out of 42 CT examinations (97.6%). One examination in group B failed due to a slightly misplaced tracker that was located too close to the pulmonary artery. At 80 kV this resulted in a premature automated start of the scan because the threshold value was reached simply due to noise while the contrast agent reached the neighboring pulmonary vessel.

**Evaluation: Image quality**

SI at the level of the common carotid artery, the bifurcation and the internal carotid artery showed significant differences toward a higher vessel attenuation in the 80 kV group B. The mean SI of the sternocleidomastoid muscle at 80 kV was nonsignificantly lower at the level of the common carotid artery but revealed a significant higher SI at the level of the bifurcation and the level of the internal carotid (Figure 1,2). Analysis of BN revealed a significant higher BN in group B at all three levels evaluated.

Despite a higher BN, CNR values showed no significantly differences at the level of the common carotid artery and the bifurcation. Due to the increased vessel attenuation the CNR was even significantly higher at that level of the internal carotid artery (p=0.002) (Figure 1).

Like CNR, SNR values did also not differ significantly at the level of the common carotid artery and the bifurcation, but showed a higher SNR at the level of the internal carotid artery in group B (p=0.05) (Figure 1).

At the evaluation of the objective image quality all vascular segments at the level of the bifurcation, the internal carotid artery in its extra- and intracranial course and the V4 segment of the vertebral artery were classified good diagnostic (score 2,3) by both readers (Figure 4). Each Reader classified 9 out of 42 (21.4%) common carotid arteries to poor image quality in group B. In group A Reader 1 classified all common carotid arteries
to good image quality (p= 0,001), reader 2 classified one out of 42 (2,4%, p=0,007) of the common carotid arteries to be of poor image quality (Figure 3,4).

All of the V1 segments in group A have been classified good diagnostic. In group B reader 1 classified 8 out of 42 (19%, p = 0,003) of the V1 segments to be of poor image quality whereas reader 2 did so in only 3 out of 42 (7,1%, p= 0,078). Each reader classified 2 out of 42 V2 segments to be of poor image quality in group B (vs. 0 in group A, p=0,152) (Figure 3,4).

An analysis of the common carotid arteries on CT scans that were rated as poor image quality in group B revealed that, with the exception of the technically unsuccessful examination, all examinations were disturbed by blurring and streak artifacts of the contrast agent that remained within the right and left brachiocephalic veins during the scan. Focusing on the V1 segments that were classified poor image quality all of them were disturbed by image noise at the upper thoracic aperture (Figure 5). All these patients were male and, with the exception of one, their BMI was above the average of group B.

In the single common carotid artery that was of poor image quality in group A was also caused by blurring of the contrast agent within the neighboring brachiocephalic vein.

**Evaluation: Radiation exposure**

There was no significant difference between the scan range in group A and B. DLP was provided by the scanner and showed a significant difference in (739±61,3 mGy*cm in Group A vs. 227,2±15,9 mGy*cm in Group B; p < 0,001). Converting the DLP of each study group into the ED by using a standard conversion factor for the head and neck region resulted in an ED of 3,99±0,33 mSv for Group A and 1,23±0,09 mSv for Group B (p < 0,001). The latter equals an average reduction of the effective dose by 69,3% (Figure 6).
### Results of signal intensities and radiation dose:

<table>
<thead>
<tr>
<th>Region</th>
<th>Parameter</th>
<th>Group A (120 kV)</th>
<th>Group B (80 kV)</th>
<th>Differences in % (B vs. A)</th>
<th>p-level</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Common Carotid Artery</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>SI vessel (HU)</td>
<td>372.8±70.2</td>
<td>590.1±120</td>
<td>58.3</td>
<td>p&lt;0.001</td>
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<tr>
<td></td>
<td>SI muscle (HU)</td>
<td>53.9±13.2</td>
<td>47.1±32.5</td>
<td>-12.6</td>
<td>n.s.</td>
</tr>
<tr>
<td></td>
<td>Background noise</td>
<td>6±1.5</td>
<td>9.6±1.9</td>
<td>60.0</td>
<td>p&lt;0.001</td>
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<tr>
<td></td>
<td>CNR</td>
<td>57.8±24</td>
<td>58.7±24.7</td>
<td>1.6</td>
<td>n.s.</td>
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<tr>
<td></td>
<td>SNR</td>
<td>118.9±53.8</td>
<td>141.3±63.1</td>
<td>18.8</td>
<td>n.s.</td>
</tr>
<tr>
<td><strong>Bifurcation</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>SI vessel (HU)</td>
<td>443.2±82.9</td>
<td>664.5±206.9</td>
<td>49.9</td>
<td>p&lt;0.001</td>
</tr>
<tr>
<td></td>
<td>SI muscle (HU)</td>
<td>60.2±8.3</td>
<td>75.1±11.7</td>
<td>24.8</td>
<td>p&lt;0.001</td>
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<tr>
<td></td>
<td>Background noise</td>
<td>3.6±1.1</td>
<td>4.4±0.9</td>
<td>22.2</td>
<td>p=0.028</td>
</tr>
<tr>
<td></td>
<td>CNR</td>
<td>118.0±53.8</td>
<td>141.3±63.1</td>
<td>19.7</td>
<td>n.s.</td>
</tr>
<tr>
<td></td>
<td>SNR</td>
<td>136.9±58.7</td>
<td>159.5±66.6</td>
<td>16.5</td>
<td>n.s.</td>
</tr>
<tr>
<td><strong>Internal carotid artery</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>SI vessel (HU)</td>
<td>396.3±55.9</td>
<td>649.9±180.6</td>
<td>64.0</td>
<td>p&lt;0.001</td>
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<tr>
<td></td>
<td>SI muscle (HU)</td>
<td>57.4±6.2</td>
<td>65.2±11.9</td>
<td>13.6</td>
<td>p=0.012</td>
</tr>
<tr>
<td></td>
<td>Background noise</td>
<td>3.4±0.7</td>
<td>4.1±0.7</td>
<td>20.6</td>
<td>p=0.03</td>
</tr>
<tr>
<td></td>
<td>CNR</td>
<td>105.1±35.5</td>
<td>145.3±42.9</td>
<td>38.2</td>
<td>p&lt;0.002</td>
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<tr>
<td></td>
<td>SNR</td>
<td>122.8±39.6</td>
<td>161.5±44.0</td>
<td>31.5</td>
<td>p=0.005</td>
</tr>
<tr>
<td><strong>Radiation Dose</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Dose Length product (mGy*cm)</td>
<td>739±61.3</td>
<td>227.2±15.9</td>
<td>-69.3</td>
<td>p&lt;0.001</td>
</tr>
<tr>
<td></td>
<td>Effective Dose (mSV)</td>
<td>3.99±0.33</td>
<td>1.23±0.09</td>
<td>-69.3</td>
<td>p&lt;0.001</td>
</tr>
</tbody>
</table>

**Fig. 0:** Results from group comparison of signal intensities and radiation dose:

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**Fig. 0:** Curved planar reformation of patients with carotid artery stenosis at the level of the bifurcation at 120 kV (A) compared to 80 kV (B). Note the increased vessel enhancement at low kV settings (B)

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**Fig. 0:** Statistical results from the evaluation of subjective image quality of 120 kV vs. 80 kV - Reader 1:

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Fig. 0: Statistical results from the evaluation of subjective image quality of 120 kV vs. 80 kV - Reader 2:

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Fig. 0: Problems of using 80 kV in CTA of the supraaortic arteries: evaluation of the thoracic aperture in obese patients. BMI 28: Image quality at 120 kV (A). BMI 25.5: Increased image noise at 80 kV but good diagnostic image quality at 80 kV (B). Streak artifacts caused by contrast agent within the right brachiocephalic vein outshining the right common carotid artery at 80 kV (C). Increased noise level results in poor image quality in a patient with a BMI of 30 (D).

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Fig. 0: Comparison of the mean Effective Dose (ED) between 80kV and 120 kV in CTA of the supraaortic arteries shows a significant difference in ED of almost 69.3% (1.23±0.09 mSv vs. 3.99±0.33 mSv; p < 0.001).

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Conclusion

This study showed that tube voltage reduction to 80 kV in CTA of the supraaortic arteries allows for significant radiation dose reduction of almost 69.3% using a 64 slice computed tomography scanner. Increased vessel attenuation at 80 kV provided confident image quality at the level of the carotid bifurcation and the intracranial runoff arteries with partially even significantly higher CNR and SNR values and an equal rating at the subjective image quality.

Focusing on the origin of the supraaortic vessels from the aortic arch there are limitations in obese patients using an 80 kV protocol. Image quality in these patients might be disturbed by streak artifacts due to contrast agent within the neighboring brachiocephalic veins and due to image noise. Therefore obese patients should be scanned at 120 kV (Figure 2).

Additionally low kV settings might open up a door for further reduction of the contrast agent amount applied during CTA as the vessel attenuation is superior compared to 120 kV.

In conclusion a low kV CTA protocol for the supraaortic arteries should be established to enable a significant dose reduction of almost up to 70% in normal weight patients with suspected arteriosclerotic disease of the head and neck vessels (Figure 3).
Fig. 0: Comparison of the mean Effective Dose (ED) between 80kV and 120 kV in CTA of the supraaortic arteries shows a significant difference in ED of almost 69.3% (1.23±0.09 mSv vs. 3.99±0.33 mSv; p < 0.001).

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Fig. 0: VRT image at 80 kV demostrating good image quality at an ED of only 1,045 mSv.

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References


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