New Contrast Injection Strategies
in Low kV and keV Imaging

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Disclosure of Commercial Interest

Consultant for / Research support from:

- Siemens
- Bayer
- Guerbet
Key Points

- Low kV and keV imaging
- Rationale for Contrast Medium Reduction
- New Protocols and Future Perspectives
Factors Involved in CM Enhancement

**Patient Factors**
- **Application:** target organs
- **Magnitude:** weight, height, cardiac output, age, gender
- **Timing:** cardiovascular (cardiac output), venous access
- **Others:** breath-holding, disease state, renal function

**CT Scanning Factors**
- **Magnitude:** scan duration, scan delay
- **Timing:** scan delay (fixed, test-bolus, bolus-tracking), scan duration
- **Others:** multi-phase scan, scan direction, ECG-gating, radiation

**Contrast Medium Factors**
- **Magnitude:** iodine mass (concentration, volume), rate, saline flush
- **Timing:** injection duration (volume, rate), saline flush, viscosity
- **Others:** injection pattern (uniphase, biphase, exponentially-decay)

- Use of lower CT tube voltages (in peak kilovolts) yields stronger contrast enhancement for a given injection of contrast medium.
- The most important patient-related factor affecting the magnitude of vascular and parenchymal contrast enhancement is body weight.
Firstly described in 2004 for Chest CT

Weight-adapted low-kV contrast-enhanced chest CT can be routinely performed at 80 kV.

Good image quality

Possible reduction of CM by more than 50%
Lower kVp yields higher iodine contrast

Higher iodine contrast compensates for higher image noise at lower kVp
Relative change in iodine dose associated with lowering or increasing kV for constant iodine enhancement [phantom experiment]

Canstein, White paper, Siemens Healthcare 2015
On the basis of the attenuation profile the algorithm automatically computes various combinations of tube voltage and tube current that result in the CNR that has been specified.

The algorithm selects the most dose-efficient combination.
Right Dose - Right Patient - Right Task
Due to current limitations in tube power, larger patients will still require higher kVp to avoid photon starvation.

Therefore, optimal kVp should be chosen individually for every patient.

“Right dose” may mean even higher kV.
### Influence of ATVS on Radiation Exposure

<table>
<thead>
<tr>
<th>Anatomic Location</th>
<th>Before ATVS</th>
<th>With ATVS Enabled</th>
<th>Change in CTDI$_{vol}$(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No. of Studies</td>
<td>CTDI$_{vol}^*$</td>
<td>No. of Studies</td>
</tr>
<tr>
<td>Head and neck</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Head CT</td>
<td>9264</td>
<td>53.1 ± 16.8</td>
<td>1656</td>
</tr>
<tr>
<td>Neck CT</td>
<td>2104</td>
<td>15.7 ± 6.1</td>
<td>711</td>
</tr>
<tr>
<td>Cerebral or carotid CT angiography</td>
<td>2019</td>
<td>25.3 ± 10.1</td>
<td>703</td>
</tr>
<tr>
<td>Cervical spine</td>
<td>1873</td>
<td>26.9 ± 12.1</td>
<td>856</td>
</tr>
<tr>
<td>Sinus of facial Bones</td>
<td>2761</td>
<td>15.9 ± 11.0</td>
<td>812</td>
</tr>
<tr>
<td>Temporal Bone</td>
<td>315</td>
<td>69.5 ± 44.4</td>
<td>61</td>
</tr>
<tr>
<td>Body</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coronary CT angiography</td>
<td>1224</td>
<td>39.8 ± 15.9</td>
<td>339</td>
</tr>
<tr>
<td>CT pulmonary angiography</td>
<td>1276</td>
<td>12.4 ± 10.0</td>
<td>916</td>
</tr>
<tr>
<td>Standard chest CT</td>
<td>12208</td>
<td>9.4 ± 4.9</td>
<td>4708</td>
</tr>
<tr>
<td>ECG-gated chest CT angiography</td>
<td>70</td>
<td>33.2 ± 11.0</td>
<td>21</td>
</tr>
<tr>
<td>Body CT angiography</td>
<td>1209</td>
<td>11.2 ± 6.1</td>
<td>744</td>
</tr>
<tr>
<td>Chest, abdomen, and pelvis</td>
<td>4217</td>
<td>13.8 ± 5.5</td>
<td>1207</td>
</tr>
<tr>
<td>Abdomen and pelvis</td>
<td>36332</td>
<td>13.3 ± 6.9</td>
<td>16066</td>
</tr>
<tr>
<td>Renal stone protocol</td>
<td>497</td>
<td>16.4 ± 8.1</td>
<td>286</td>
</tr>
<tr>
<td>Thoracic lumbar spine</td>
<td>2903</td>
<td>22.6 ± 14.6</td>
<td>833</td>
</tr>
<tr>
<td>CT colonoscopy</td>
<td>171</td>
<td>10.6 ± 5.5</td>
<td>67</td>
</tr>
<tr>
<td>Extremities</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shoulder</td>
<td>193</td>
<td>19.9 ± 17.5</td>
<td>67</td>
</tr>
<tr>
<td>Hip and bony pelvis</td>
<td>251</td>
<td>12.3 ± 6.6</td>
<td>73</td>
</tr>
<tr>
<td>Peripheral runoff CT angiography</td>
<td>388</td>
<td>7.0 ± 4.4</td>
<td>187</td>
</tr>
<tr>
<td>All examinations</td>
<td>79275</td>
<td>NA</td>
<td>30313</td>
</tr>
</tbody>
</table>
Approaching Iodine K-edge

Iodine K-edge 33.2 keV

Stolzmann P Insight Radiol 2011
Intracranial Circulation

80 kVp - 30 ml

120 kVp - 60 ml

Ni QQ, De Cecco AJNR 2016
Intracranial Circulation

80 kVp - 30 ml

Ni QQ, De Cecco AJNR 2016
CCTA in Obese Patients

In conclusion, our results demonstrate that CCTA and TRO-CT can be routinely performed in obese patients even with a BMI of more than 40 kg/m² with consistent diagnostic image quality using a 3rd generation DSCT scanner with a tube voltage of 120 kV and a contrast material volume of approximately 80 ml.

BMI 25-30  BMI 30-40  BMI >40

Mangold S, De Cecco CN Eur Radiol 2016
CCTA

50 ml CM
Objective

Image Quality

Low kV, ATVS and IR

Fixed 120 kv - FBP

20 mSv
110 ml CM

3.9 mSv
60 ml CM

Superior

70 kv ATVS - IR
Mangold S, De Cecco CN EJR 2016
Aorta

100 kVp - 60 ml

70 kVp - 40 ml

Geyer LL, De Cecco CN Acad Radiol 2015
Excellent Image Quality

80 kV
50 ml CM
Mixed
120 kVp

CM  70 ml

Wichmann JL, De Cecco Invest Radiol 2015
Iodine load can be reduced by 33% in CT of the liver with 80 kVp and ASIR technique

### Parenchymal Organs

<table>
<thead>
<tr>
<th>Parameters</th>
<th>600 mg/kg–120 kVp (n = 60)</th>
<th>500 mg/kg–80 kVp (n = 50)</th>
<th>400 mg/kg–80 kVp (n = 60)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patient age (y)</td>
<td>68.2 ± 10.1 (48–84)</td>
<td>68.4 ± 11.8 (41–85)</td>
<td>67.5 ± 10.0 (40–84)</td>
</tr>
<tr>
<td>Male:female</td>
<td>39:21</td>
<td>33:17</td>
<td>42:18</td>
</tr>
<tr>
<td>Body weight (kg)</td>
<td>59.0 ± 9.4 (32–78)</td>
<td>58.0 ± 10.7 (38–89)</td>
<td>59.2 ± 9.7 (38–81)</td>
</tr>
<tr>
<td>Body mass index</td>
<td>23.0 ± 2.9 (15.9–30.6)</td>
<td>22.2 ± 3.1 (16.4–28.7)</td>
<td>22.7 ± 3.3 (15.8–29.1)</td>
</tr>
<tr>
<td>Iodine weight (g)</td>
<td>35.3 ± 5.6 (19.2–46.8)</td>
<td>29.3 ± 5.5 (19.0–44.5)</td>
<td>23.7 ± 3.9 (15.2–32.4)</td>
</tr>
</tbody>
</table>

Noda Y Eur J Radiol 2014

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(a) ![Image](image1.png)
(b) ![Image](image2.png)

<table>
<thead>
<tr>
<th>Group</th>
<th>Sensitivity (%)</th>
<th>Specificity (%)</th>
<th>AUC (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>600 mg/kg–120 kVp</td>
<td>92</td>
<td>100</td>
<td>0.99 (0.92–1.00)</td>
</tr>
<tr>
<td>500 mg/kg–80 kVp</td>
<td>100</td>
<td>97</td>
<td>0.99 (0.91–1.00)</td>
</tr>
<tr>
<td>400 mg/kg–80 kVp</td>
<td>92</td>
<td>100</td>
<td>0.99 (0.93–1.00)</td>
</tr>
</tbody>
</table>
Combining 80 kVp with IR allows at least a 47% contrast agent dose reduction and 16% radiation dose reduction for images of comparable quality.

Buls N Eur Radiol 2014
Low Kv and Low CM

90 kV

39 M, BMI 21.2

Crohn

CM: 100 ml  350 mgI/ml
mSv 4
Low kV/keV protocols can significantly decreased the amount of CM

What is the minimum IDR/Contrast Volume we can achieve in clinical practice?
Identical TAC – 50% CM reduction in pigs

Lell MM Invest Radiol 2015
1st patients’ cohort

- Relative difference of Iodine attenuation at 120 kVp to each tube voltage was used to calculate the amount of CM reduction to achieve equal vascular attenuation (300-350 HU set as target).
- Flow rate was adapted to maintain 19 sec of bolus injection.

<table>
<thead>
<tr>
<th>Tube Voltage (kVp)</th>
<th>CM Volume (mL)</th>
<th>Quantity of Iodine* (g)</th>
<th>Flow Rate (mL/sec)</th>
<th>Iodine Delivery Rate (g/sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>80</td>
<td>45</td>
<td>18</td>
<td>2.4</td>
<td>0.00096</td>
</tr>
<tr>
<td>90</td>
<td>53</td>
<td>21.2</td>
<td>2.9</td>
<td>0.00116</td>
</tr>
<tr>
<td>100</td>
<td>61</td>
<td>24.4</td>
<td>3.2</td>
<td>0.00128</td>
</tr>
<tr>
<td>110</td>
<td>68</td>
<td>27.2</td>
<td>3.6</td>
<td>0.00144</td>
</tr>
</tbody>
</table>
Aortic-CTA with Tailored CM reduction

Results

Tube Voltage

80
90
100
110

Higashigaito K Radiology 2016
Optimizing Contrast Medium Injection

Contrast Reduction at Low kVp and keV
Which is the minimum IDR and CM volume required to obtain 350 HU in the aorta at different kV and keV?

Two-phases study:
1. Fixed CM amount @ different IDR
2. Fixed IDR lowering CM amount
Optimizing Contrast Medium Injection

All IDR s reached 350 HU (p≥0.18)
Optimizing Contrast Medium Injection

Adequate Time-To-Peak is mandatory
Optimizing Contrast Medium Injection

2nd approach: Constant IDR and lowering CM amount
A combined approach reducing the CM volume for tube voltages <120 kV and increasing the IDR for higher kV settings seems the most effective approach.
Radiation Dose Monitoring

- Force
- Flash
- Definition

Per-scanner dose monitoring
Radiation and CM Dose Combined Monitoring

- Per-Patient Dose Monitoring
- Protocol Optimization
What Future?

Body Morphology and Weight

Personalized Radiation & Contrast Dose
Low kV and keV studies increase Iodine Contrast Enhancement allowing for a significant reduction in contrast media volume

New IDR-based injection strategies could further improve contrast medium tailoring

Patient-tailored Radiation and Contrast Dose (Kg >> kV/keV >> IDR)
Thanks for the attention!
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