Influence of different iteration levels in fourth generation iterative reconstruction technique on image noise in CT examinations of the neck

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Purpose

Over the last decades, numbers of CT-examinations have increased strikingly [1] on page 1. In 1980, three million CT-scans were performed in the USA - within the next 30 years, the number of examinations rose steadily to about 62 millions.

In 2006, CT scans amounted to about 60% of overall medical radiation exposure, whilst holding only a small share of seven percent of all radiological procedures [2] on page 1.

These numbers illustrate the importance of the reasonable use of ionizing radiation and dose reduction in CT. The widely accepted and adapted ALARA-Principle (as low as reasonably achievable) demands the minimization of risk for maximum diagnostic benefit.

Dose reduction thus being a major concern, different approaches have been made to minimize radiation exposure, among them automatic dose control systems in CT examinations.

Those systems automatically adapt tube settings to patient size and can also modify the tube load dynamically during the scan in x-, y- and z-axis to reduce radiation exposure. They can also relate to a physiologic signal like an ECG or can keep noise levels constant by online modulation of the tube load.

So far, the goal of economizing radiation dose was limited by the use of Filtered Back-Projection technique for image reconstruction - significant dose reduction quickly lead to high image noise levels, degradation in spatial resolution and artefacts.

Iterative image reconstruction techniques are able to reduce image noise while maintaining other parameters like image sharpness, thus allowing the user to reduce radiation without having to lower one's sights regarding image quality.

The objective of our study was to evaluate the effect of the fourth-generation, raw data based, iterative reconstruction technique (IRT) iDose4 (Philips Healthcare, Best, Netherlands) compared to traditional reconstruction with filtered back-projection (FBP) on image noise in a representative group of patients undergoing neck CT-examinations. Unlike previous iterative reconstruction systems which have been available for a while, it works in both raw data and image space data area (see figure 1).
**Fig. 1:** Illustration of the basic principle of iterative reconstruction technique with iteration in raw data space AND image space.

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Methods and Materials

Population studied
The study population consisted of 20 consecutive patients planned to receive a clinically indicated CT examination of the neck.

General exclusion criteria included age below 18, pregnancy as well as, for contrast-enhanced scans, renal insufficiency, hyperthyroidism and hypersensitivity to iodine-containing contrast media. Additionally, patients with tumours of the ENT-Section (ear-nose and throat) were excluded.

Patient demographics are summarized in table 1.

<table>
<thead>
<tr>
<th>Sex</th>
<th>Age [yrs]</th>
<th>Height [cm]</th>
<th>Weight [kg]</th>
<th>BMI (kg/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6f, 14m</td>
<td>59.4 ± 15.1</td>
<td>173.3 ± 8.6</td>
<td>74.5 ± 17.0</td>
<td>24.6 ± 4.4</td>
</tr>
</tbody>
</table>

Table 1: Patient demographics.

Acquisition protocol
All examinations were performed on a 64-slice CT (Brilliance 64, Philips Healthcare, Best, Netherlands) with a tube voltage of 120kV and a tube load of 180 mAs (protocol mAs = standard mAs for average patient, modified by automatic current selection and longitudinal dose modulation according to patient size).

For each patient, the dose-length product (DLP) and CT dose index volume (CTDI vol) were recorded along with patient weight and height.

Further CT parameters are described in table 2.

<table>
<thead>
<tr>
<th>kV</th>
<th>mAs (protocol)</th>
<th>mAs (planned)</th>
<th>mAs (average)</th>
<th>mAs (max)</th>
<th>mAs (min)</th>
<th>ACS (automatic current selection)</th>
<th>DOM (dose modulation)</th>
<th>Adaptive Filter</th>
</tr>
</thead>
<tbody>
<tr>
<td>120</td>
<td>180 ± 0</td>
<td>253 ± 114.1</td>
<td>145 ± 67.1</td>
<td>249 ± 113.1</td>
<td>77 ± 34.0</td>
<td>Yes</td>
<td>LDM (longitudinal dose modulation)</td>
<td>Yes</td>
</tr>
</tbody>
</table>
Scan-length (mm) 214 ± 30.8
CTDIvol (mGy) 8.6 ± 4.0
DLP (mGy x cm) 237 ± 115.6
Effective dose* (mSv) 2.4 ± 1.2
Collimation 64 x 0.625 mm
Pitch 1.01

Table 2: CT parameters and settings; *Effective dose (mSv) = DLP x scaling factor (=0.01 for neck)

**Image reconstruction**

Raw data were collected from the CT-scanner and reconstructed with a prototype image reconstruction system for each patient using FBP as well as IRT with different iteration levels.

Following levels were applied:

iDose Level 2 - meant to compensate 30% mAs-reduction,
iDose Level 4 - meant to compensate 50% mAs-reduction, with and without Multiresolution
iDose Level 6 - meant to compensate 70% mAs-reduction, with and without Multiresolution
iDose Level 7 - meant to compensate 80% mAs-reduction, with and without Multiresolution

Multiresolution is an option to refine image noise, which can be added to the reconstruction in every iteration level.

The iterative reconstruction algorithm (illustrated in figure 1) starts with projection data, where it identifies and corrects the noisiest CT measurements (those with very poor signal to noise ratio or very low photon counts). This process is meant to prevent low signal streaks and bias errors.

Furthermore, the iDose4 algorithm deals with subtraction of the image noise in the image volume. Data dependant noise and structural models are used iteratively to eliminate the quantum image noise while preserving the underlying edges associated with changes in the anatomic structure - thus preserving spatial resolution while allowing a significant noise reduction.

All datasets were reconstructed using two different soft tissue kernels (B and C; see figures 2 and 3), a slice thickness of 5 mm and an increment of 5 mm.
Standard soft tissue window settings (C60/W350) were applied. All images were transferred to a dedicated CT-workstation (Extended Brilliance Workspace, Philips Healthcare) for further assessment.

**Image quality evaluation**

Resulting images were analysed with objective noise measurements. Therefore, two regions of interest (ROI) of about 30 mm² in size were placed in a homogenous region of the M. erector spinae and the myelon, respectively (see figure 4). Both measures were done twice. Mean noise was calculated as standard deviation of average density values within these regions.
**Fig. 1:** Illustration of the basic principle of iterative reconstruction technique with iteration in raw data space AND image space.

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Fig. 2: Neck CT image, reconstructed with soft tissue kernel "B" (=standard soft tissue reconstruction with filtered back projection).

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Fig. 3: Neck CT image, reconstructed with soft tissue kernel "C" (=slightly sharper reconstruction kernel than "B"; filtered back projection).

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Fig. 4: Cross section of neck CT with illustration of the sites, where ROIs were placed for measurement of noise levels (myelon and M. erector spinae).

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Results

Absolute noise levels were reduced from 8.10 (FBP) to 3.88 HU (highest level IRT) using kernel B and from 11.41 to 5.00 HU with kernel C.

Relative noise in IRT-images compared to FBP-images was reduced to 48% with kernel B and to 44% with kernel C. Complete results are listed in tables 3 and 4.

<table>
<thead>
<tr>
<th></th>
<th>FBP</th>
<th>iDose-level 2</th>
<th>iDose-level 4</th>
<th>iDose-level 4 +MR</th>
<th>iDose-level 6</th>
<th>iDose-level 6 +MR</th>
<th>iDose-level 7</th>
<th>iDose-level 7 +MR</th>
</tr>
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<tbody>
<tr>
<td>absolute noise levels</td>
<td>8.10±1.87</td>
<td>6.27±1.59</td>
<td>5.03±1.49</td>
<td>4.71±1.45</td>
<td>4.39±1.41</td>
<td>3.91±1.26</td>
<td>4.36±1.39</td>
<td>3.88±1.20</td>
</tr>
<tr>
<td>(HU) ± SD</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>relative noise</td>
<td>1</td>
<td>0.77</td>
<td>0.62</td>
<td>0.58</td>
<td>0.54</td>
<td>0.48</td>
<td>0.53</td>
<td>0.48</td>
</tr>
<tr>
<td>levels (compared to FBP)</td>
<td></td>
<td></td>
<td></td>
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<td></td>
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</tbody>
</table>

Table 3: Averaged noise levels for CT images of the neck, reconstructed with kernel "B" with filtered back projection (FBP) and different levels of iterative reconstruction. MR = Multiresolution
Table 4: Averaged noise levels for CT images of the neck, reconstructed with kernel "C" with filtered back projection (FBP) and different levels of iterative reconstruction. MR = Multiresolution

For illustration of reduced noise and smoother image appearance caused by IRT figures 3 (FBP), 5 (IRT Level 4) and 6 (IRT Level 7) are presented here.
Images for this section:

**Fig. 3:** Neck CT image, reconstructed with soft tissue kernel "C" (=slightly sharper reconstruction kernel than "B"; filtered back projection).

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Fig. 5: Neck CT image, reconstructed with soft tissue kernel "C" (=slightly sharper reconstruction kernel than "B"; iterative reconstruction Level 4). Note the smoother appearance of soft tissue compared to FBP-image (Figure 2 and 3).

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Fig. 6: Neck CT image, reconstructed with soft tissue kernel "C" (=slightly sharper reconstruction kernel than "B"; iterative reconstruction Level 7). Note the much smoother appearance of soft tissue compared to FBP-image (Figure 2 and 3) as well as compared to Level 4 iterative reconstruction (Figure 5).

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Conclusion

Use of IRT for CT-examinations of the neck results in a reduction of image noise of up to 56%.

Prospectively, iterative reconstruction techniques like iDose will allow a significant reduction of radiation exposure by lucidly reducing image noise and thus allowing dose minimization whilst maintaining image quality.

However, clinical applicability can only be evaluated conclusively considering subjective image quality and diagnostical assessment, which is being evaluated by our study group at present.
References

[1] Deutsches Ärzteblatt online (letzter Zugriff 29.01.2012):

[2] Ärztezeitung online (letzter Zugriff 29.01.2012):