Dose reduction using a CT iterative reconstruction algorithm with low tube voltage and exposure

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Purpose

Nowadays the development of iterative reconstruction algorithms for CT scanners has opened the possibility to strongly reduce dose levels in CT. These algorithms reduce the amount of noise in respect to the standard Filtered Back Projection (FBP) reconstructed images, therefore allowing to a reduction of the dose maintaining the Signal to Noise Ratio (SNR) constant. However, iterative reconstruction is known to cause a modification in the Noise Power Spectrum (NPS) that can result in an increase of noise in a specific frequency range, even if the global SNR is unchanged [1-3]. Another possible way to reduce dose in iodine contrast enhanced CT is to reduce the tube voltage from 120 kV to 80 - 100 kV [4].

The purpose of this work is to combine iterative reconstruction algorithms with low tube voltage to decrease the dose levels, maintaining the Contrast to Noise Ratio (CNR) constant and preventing a degradation of the noise in any frequency. The study will analyze a typical protocol for contrast enhanced CT abdomen.
Methods and Materials

CT SCANNER - ACQUISITION PROTOCOL
The CT scanner used is the Philips Brilliance 64 with Philips iterative reconstruction system, iDose®. The CT scanner can reconstruct images in standard FBP mode or with iDose algorithm at different levels of strength. The levels range from 1 to 7; the studied levels were 2, 4, 6.
The acquisition protocol was defined on the basis of a clinical contrast enhanced abdomen protocol. The parameters used are:
- Modality: axial;
- Filter: B;
- Resolution: high;
- Exposure: 200 mAs;
- Rotation: 0.75 s;
- Collimation: 64 x 0.625 mm;
- Reconstructed thickness: 1.25 mm;
- Optimization: 0.

NPS WITH IDOSE
A water phantom was scanned at 120 kV and the reconstructions were obtained with FBP and with the studied iDose levels. The NPS was calculated for each reconstruction using the software ImageJ (http://rsbweb.nih.gov) and the analysis tool "QA-distri" (http://qa-distri.sourceforge.net). The mean frequency of the noise distribution was evaluated and compared to the one obtained with the FBP reconstruction for a quantitative evaluation of the distortion of the spectra caused by the iterative reconstruction. For each level, the mAs equivalent value in order to have a conservative NPS - never worse than the reference FBP NPS in any frequency range - was calculated.

CNR DEPENDENCE ON TUBE VOLTAGE
Three solutions of water and iodine contrast agent (Iopamiro® 370 - Bracco) were prepared with concentrations of 2.5%, 3.75% and 5%. These contrast solutions in CT images have CT numbers between 200 and 400 HU at 120 kV; this is a typical range observed in clinical details uptaking contrast.
The acquisitions were performed at 120, 100 and 80 kV using a CTDI body phantom with the three contrast solutions alternatively inserted in the central and lateral holes (Figure 1). We used the CTDI body phantom to simulate the absorption in a clinical situation. For each image, the CNR of the contrast solutions were evaluated and compared with the 120 kV CNR value, in order to obtain the achievable dose at 100 kV and at 80 kV to match the CNR at 120 kV.
Fig. 1: CT scan of the CTDI phantom used for the measurements of CNR at different tube voltages and with different contrast solutions. In this scan, the central compartment hosts the middle concentration solution (3.75%), the left compartment the low concentration solution (2.5%) while the right one contains the high concentration solution (5%).

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Results

NPS WITH IDOSE
Reconstructed images with FBP and the studied iDose levels (Figure 2) and the calculated NPS (Figure 3) show the iDose algorithm effect of noise reduction. The same spectra normalized by the variance of the respective images (Figure 4) give a qualitatively picture of the distortion caused by the iterative reconstruction. iDose causes a spread of the spectrum, increasing the percentage of noise at low frequency (< 3 lp/cm), reducing the percentage of middle frequency noise (between 3 lp/cm and 5 lp/cm) and leaving the high frequency noise (from 5 lp/cm to the Nyquist frequency) unchanged. This trend is also quantitatively spotted out by the evaluation of the mean frequency of the spectra, which decreases for higher iDose levels (Table 1).

For each level, the mAs equivalent values are reported in Table 1. In the clinical practice, the distortion on the noise appearance is reported to be acceptable until the 4th level of strength. The mAs equivalent value, and therefore the dose, for this level is 79% in respect to the standard FBP.

CNR DEPENDENCE ON TUBE VOLTAGE
The dependence of signal and noise of the three contrast solutions on different tube voltage, with the same mAs value (200 mAs), is plotted in Figure 5. The signal of the contrast solution increases, as expected, lowering the tube voltage and for increasing contrast concentration, while noise increases lowering the tube voltage but does not depend on the solution concentration. This causes the CNR to behave differently for the different contrast solutions, as shown in Table 2. In particular, at low contrast concentration (2.5%) the CNR increases lowering the tube voltage; at intermediate concentrations (3.75%) the CNR is almost independent on the tube voltage; at high concentration the CNR decreases when we decrease the tube voltage. Therefore, further considerations on dose reduction were limited to the case of the highest concentration, since it is conservative also for lower contrast concentrations.
CNR trend - and therefore the dose achievable - depends also on the CT number of the background. The phantom used in the measurement has a mean CT number of 135 HU at 120 kV, while the anatomic structures of interest in contrast enhanced abdominal CT range from 40 HU to 60 HU. The dose achievable dependence on the background CT number is shown in Figure 6. For each of the three background values considered, the dose achievable was calculated (Table 3).

FINAL DOSE ACHIEVABLE
Using both iDose algorithm at level 4 and low tube voltage, a final dose level can be obtained in order to keep the CNR constant and a conservative NPS in respect to the reference 120 kV FBP reconstruction case. Table 4 shows the estimated values in representative anatomical districts.
Fig. 2: Qualitative behavior of the iDose algorithm. The CT images were taken from a single acquisition of the water phantom and cropped to visualize the noise associated with the water signal. (a) standard Filtered Back Projection (FBP) reconstruction; (b) iDose 2 reconstruction; (c) iDose 4 reconstruction; (d) iDose 6 reconstruction. The images highlight the iDose algorithm effect of noise reduction.

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Fig. 3: Noise Power Spectra (NPS) of the images in Figure 2.

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Fig. 4: The same spectra of Figure 3 were normalized by the variance in order to have a qualitative comparison of their shape. iDose causes a spread of the spectrum, increasing the percentage of noise at low frequency (< 3 lp/cm), reducing the percentage of middle frequency noise (between 3 lp/cm and 5 lp/cm) and leaving the high frequency noise (from 5/cm to the Nyquist frequency) unchanged.

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Table 1: The mean frequencies of NPS shown in Figure 4 are reported. Comparing the values, we have a measure of the distortion of the NPS caused by iDose algorithm. In the table are also shown the mAs equivalent values in order to assure NPS conservativity, that is having iDose NPS below the FBP reference one in Figure 4. IDose levels above the 4th cause a distortion considered not acceptable by radiologists in clinical analysis.

<table>
<thead>
<tr>
<th>iDose level</th>
<th>NPS mean frequency (lp/cm)</th>
<th>mAs equivalent</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 (FBP)</td>
<td>4.60</td>
<td>100%</td>
</tr>
<tr>
<td>2</td>
<td>4.57</td>
<td>88%</td>
</tr>
<tr>
<td>4</td>
<td>4.54</td>
<td>79%</td>
</tr>
<tr>
<td>6</td>
<td>4.50</td>
<td>51%</td>
</tr>
</tbody>
</table>
Fig. 5: (a) Dependence of the CT number of the contrast solutions on the tube voltage. As expected, the CT number increases lowering the tube voltage and for increasing contrast concentrations. (b) Dependence of the noise (standard deviation) of the contrast solutions on the tube voltage. As expected, noise increases lowering the tube voltage, independently on the solution concentration.

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Table 2: Evaluation of Contrast to Noise Ratio (CNR) and its dependence on tube voltage and on contrast concentration.

<table>
<thead>
<tr>
<th>Tube voltage (kV)</th>
<th>CNR</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Contrast concentration: 5%</td>
<td>Contrast concentration: 3.75%</td>
<td>Contrast concentration: 2.5%</td>
</tr>
<tr>
<td>120</td>
<td>5.24</td>
<td>3.22</td>
<td>1.42</td>
</tr>
<tr>
<td>100</td>
<td>5.12</td>
<td>3.37</td>
<td>1.81</td>
</tr>
<tr>
<td>80</td>
<td>4.37</td>
<td>3.11</td>
<td>1.83</td>
</tr>
</tbody>
</table>

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**Fig. 6:** Dependence of the dose achievable on the CT value of the background. The black line corresponds to the phantom background, while the yellow stripe refers to the anatomical background range. Low background CT numbers result in less advantage in terms of dose reduction for low voltages.

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### Table 3: Achievable dose values at 100 kV and at 80 kV to match the CNR at 120 kV for the background values of interest (phantom and anatomical structures).

<table>
<thead>
<tr>
<th>Tube voltage (kV)</th>
<th>Background 135 HU (phantom)</th>
<th>Background 60 HU</th>
<th>Background 40 HU</th>
</tr>
</thead>
<tbody>
<tr>
<td>120</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>100</td>
<td>64%</td>
<td>76%</td>
<td>78%</td>
</tr>
<tr>
<td>80</td>
<td>44%</td>
<td>62%</td>
<td>65%</td>
</tr>
</tbody>
</table>

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Table 4: Summary of the dose achievable values using both iDose and low tube voltages for different backgrounds. The dose can be reduced by 40% or 50% respectively using 100 kV or 80 kV with iDose 4, still maintaining the CNR constant and a conservative NPS in respect to the reference 120 kV FBP reconstruction case.

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<table>
<thead>
<tr>
<th>Tube voltage (kV)</th>
<th>Background 60 HU</th>
<th>Background 40 HU</th>
</tr>
</thead>
<tbody>
<tr>
<td>120</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>100</td>
<td>60%</td>
<td>61%</td>
</tr>
<tr>
<td>80</td>
<td>49%</td>
<td>52%</td>
</tr>
</tbody>
</table>
Conclusion

Dose can be reduced in contrast enhanced CT images lowering the tube voltage from 120 kV to 100 - 80 kV and maintaining the CNR unchanged. A further reduction by means of a proper usage of the iterative algorithm, leads to respectively 60% and 50% of the reference 120 kV FBP dose value. Due to the NPS dependence on the reconstruction filter, the resolution and the optimization parameters, the results are CT protocol-dependent.
References


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