Evaluation of an iterative reconstruction algorithm (iDose): applications in computed tomography coronary angiography (CTCA).

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Aims and objectives

Coronary CT angiography (CCTA) is a noninvasive imaging technique widely used for the assessment of coronary artery disease (CAD). It provides high diagnostic performance that is constantly increasing as the CT technology advances [1]. CCTA is performed either by subsequent axial scans (step-and-shoot mode) on a predefined phase of the cardiac cycle (prospective ECG- triggered technique), a mode which is associated with a substantial reduction of radiation exposure for the patient, or by a continuous helical (or spiral) scan acquiring data throughout the cardiac cycle during several heart beats (retrospective ECG- gated technique).

Regardless of the scanning method, CCTA remains an examination with high radiation exposure and its relevance to cancer induction remains a major concern [2-4]. In response to this concern, various techniques to reduce radiation exposure in CCTA have been implemented. Improved detector technology, adaptive collimation, use of automatic exposure control (AEC), dose modulation and filtering techniques are some steps towards that direction [5,6]. An important limitation to further reducing radiation dose is the currently adopted image reconstruction technique, namely filter back projection (FBP). Iterative reconstruction (IR) algorithms have been recently developed to overcome the limitation of FBP and in recent years, various IR algorithms have become commercially available from various CT scanner manufacturers [7]. The adoption of these commercially available IR algorithms in clinical practice has resulted in image quality (IQ) improvement compared to the standard FBP algorithms [8-13] and adjustment of CCTA protocols to the new IR algorithms has led to considerable radiation dose reduction ranging between 40% and 63% compared to FBP protocols while maintaining IQ [14-18].

The purpose of this study was to assess the impact of such an IR algorithm iDose 4 (Philips Healthcare, Cleveland, OH, USA) on IQ compared to FBP for both retrospective ECG-gated and prospective ECG-triggered CCTA protocols and to evaluate achievable radiation dose on a 64-MDCT scanner.

Methods and materials

Materials and Methods

Patient population

Our study included 58 patients (36 men, 57.1 ± 15.4 years) with known or suspected CAD who were referred for CCTA at our department between June 2011 and August
2013. These patients were classified into 4 groups according to the acquisition mode (prospective ECG-triggered or retrospective ECG-gated) and the acquisition settings.

**CCTA data acquisition and reconstruction**

All patients were examined on a 64-slice CT scanner (Brilliance- 64, Philips Medical Systems, Cleveland, OH, USA). CCTA examinations were performed using either retrospective helical ECG-gated or prospective axial ECG-triggered protocol. The selection of the acquisition protocol was based on the heart rate of each patient: patients with heart rate < 60 bpm were scanned in axial mode and patients with heart rates > 65 bpm were scanned in helical mode. In patients with intermediate heart rates (60 to 65 bpm), other parameters were also considered in the selection of the acquisition mode such as BMI and the effective diameter of the patient.

The tube potential and the tube current-time product were selected based on the BMI of patients. Patients who were examined after the installation of iDose\(_4\) were scanned with a tube current reduced by 45\% for helical acquisition and 30\% for axial acquisition compared to the patients underwent CCTA examinations with the FBP protocol. In order to reach the aforementioned exposure reduction, exposure parameters were gradually reduced according to the manufacture's recommendations.

According to the acquisition method and reconstruction algorithm adopted patients were classified into 4 groups. All images for both acquisition modes were reconstructed at 75\% of the cardiac cycle. Raw data of groups 1 and 2 were reconstructed with FBP and iDose\(_4\) of levels 4 and 6 (50\% and 70\% IR blending with FBP algorithm) while raw data of groups 3 and 4 were reconstructed only with FBP algorithm. (Table in Figure 1)
The demographic characteristics of the patients for each group are presented in the table in figure 2.

Fig. 1

References: National Kapodistrian University of Athens, 2nd Department of Radiology, General University Attikon Hospital - Chaidari/GR
Fig. 2

References: National Kapodistrian University of Athens, 2nd Department of Radiology, General University Attikon Hospital - Chaidari/GR

No significant age or effective diameter differences between the four groups were evident (p = 0.77 and p=0.63 respectively). No significant differences in heart rates were evident for the patients in the helical group between iDose4 and FBP reconstruction (p=0.254) and similarly in the spiral group between iDose4 and FBP reconstruction (p=0.988).

Image quality evaluation

All reconstructed images were transferred for quantitative and qualitative analysis to a DICOM-compatible PACs workstation.

Objective IQ evaluation was conducted with region of interest (ROI) analysis in the axial CCTA images for all reconstructions: a 2 cm$^2$ circular ROI was located in the aortic root at the level of the left main coronary artery and two rhomboid ROIs of 0.5 cm$^2$ each were located at the left lateral ventricular myocardium and interventricular septum Fig. 3 on page 7. The mean values of the two myocardium ROIs were used in the calculations. Signal-to-noise ratio (SNR) and contrast-to-noise ratio (CNR) were calculated as seen in Figure 4.
Subjective image quality evaluation was performed independently by two experienced radiologists with more than 5 years experience in CCTA examinations on both axial sections and curved multiplanar reconstructions of the coronary arteries. Both radiologists were blinded to the technical and clinical information of CT images. A 5-point scale was used for subjective image evaluation (Table in Figure 5).
Radiation exposure estimation

Volume CT dose index (CTD1vol) and dose length product (DLP) were recorded from the console display of the CT scanner. To obtain the effective dose (ED), dose-length product was multiplied by an appropriate gender and body habitus averaged conversion coefficient for the adult thorax ($k=0.0147$ mSv·mGy-1·cm-1) [19].
Fig. 3: Top: Placement of a ROI of the same size and shape in axial images at the appropriate location in the ascending aorta for all reconstructions. Bottom: Curved MPR of the LAD branch for all reconstructions demonstrating reduction of noise, evident through visual assessment.
Results

*Dose reduction achieved with the use of iDose$_4$*

The resulting calculated effective doses for the four groups are presented as a box plot in Figure 6.

![Box plot showing dose reduction](image)

**Fig. 6**

**References:** National Kapodistrian University of Athens, 2nd Department of Radiology, General University Attikon Hospital - Chaidari/GR

Significant effective dose reduction of 27.3% (from 3.3±1.1 mSv to 2.4±0.8 mSv) and 43.3% (from 15.0±3.1 mSv to 8.5±2.5 mSv) were recorded respectively in axial and helical acquisition with the use of iDose$_4$ compared to FBP. Scanning with prospective...
acquisition was associated with ~75% lower calculated effective doses compared to retrospective acquisition for both iDose₄ and FBP.

Objective IQ measurements (Table in Figure 7)

<table>
<thead>
<tr>
<th>Group</th>
<th>No.</th>
<th>Noise_aorta</th>
<th>No.</th>
<th>Noise_myoc</th>
<th>SNR_aorta</th>
<th>CNR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group 1</td>
<td>L4</td>
<td>38.5 ± 10.1</td>
<td>L6</td>
<td>31.7 ± 8.3</td>
<td>10.5 ± 2.4</td>
<td>12.9 ± 3.2</td>
</tr>
<tr>
<td>Group 2</td>
<td>L4</td>
<td>31.3 ± 6.1</td>
<td>L6</td>
<td>24.7 ± 4.9</td>
<td>12.7 ± 3.5</td>
<td>16.2 ± 4.5</td>
</tr>
<tr>
<td>Group 3</td>
<td>FBP</td>
<td>30.2 ± 6.1</td>
<td>FBP</td>
<td>37.9 ± 12.7</td>
<td>11.2 ± 3.5</td>
<td>5.6 ± 1.6</td>
</tr>
<tr>
<td>Group 4</td>
<td>FBP</td>
<td>58.9 ± 17.0</td>
<td>FBP</td>
<td>54.1 ± 14.8</td>
<td>6.9 ± 1.8</td>
<td>3.6 ± 1.1</td>
</tr>
</tbody>
</table>

Fig. 7

References: National Kapodistrian University of Athens, 2nd Department of Radiology, General University Attikon Hospital - Chaidari/GR

The 43% radiation exposure reduction in spiral acquisitions with iDose₄-L4 resulted to significant noise increase compared to FBP both at the aorta (27%, p=0.016) and the myocardium (21%, p=0.036). Howeve reconstruction with iDose₄- L6 led to noise levels that were similar to those in FBP images acquired with full exposure settings (group 3) (p= 0.75 for aorta and p= 0.9 for myocardium). The differences of SNR and CNR between
iDose\textsubscript{4}-L4 and L6 and FBP images were not significantly different (p=0.058 and p= 0.975 for SNR, p=0.166 and p= 0.811 for CNR).

In axial acquisition, 23% radiation exposure reduction resulted to non-significant differences between the iDose\textsubscript{4}-L4 and FBP for noise (p=0.219 for aorta and p=0.339 for myocardium), SNR (p=0.473) and CNR (p=0.562). The implementation of the most powerful iDose L6 led to significant image quality improvement of 34.8% (p= 0.003), 31.0% (p= 0.014), 44.6% (p= 0.015), and 30% (p= 0.022) corresponding to aorta noise, myocardium noise, SNR and CNR indices.

Subjective IQ measurements (Table in Figure 8)

<table>
<thead>
<tr>
<th>Table 5. Subjective IQ</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Group 1 (iDose+spiral)</td>
</tr>
<tr>
<td>FBP</td>
</tr>
<tr>
<td>L4</td>
</tr>
<tr>
<td>L6</td>
</tr>
</tbody>
</table>

| Group 2 (iDose+axial)  |       |           |        |           |                     |
| FBP                    | 2.7 ± 0.4 | 2.5 ± 0.5 | 2.6 ± 0.4 | 2.5 ± 0.6 | 2.5 ± 0.7           |
| L4                     | 2.1 ± 0.3 | 2.3 ± 0.4 | 2.2 ± 0.4 | 2.4 ± 0.7 | 2.1 ± 0.9           |
| L6                     | 1.9 ± 0.4 | 2.3 ± 0.4 | 2.3 ± 0.4 | 2.3 ± 0.7 | 2.1 ± 0.8           |

| Group 3 (FBP+spiral)   |       |           |        |           |                     |
| FBP                    | 2.5 ± 0.6 | 2.7 ± 0.6 | 2.5 ± 0.7 | 2.4 ± 0.9 | 2.4 ± 1.0           |
| L4                     | 2.4 ± 0.4 | 2.2 ± 0.7 | 2.2 ± 0.5 | 1.8 ± 0.5 | 2 ± 0.9             |
| L6                     | 2.4 ± 0.4 | 2.2 ± 0.7 | 2.2 ± 0.5 | 1.8 ± 0.5 | 2 ± 0.9             |

| Group 4 (FBP+axial)    |       |           |        |           |                     |
| FBP                    | 2.4 ± 0.4 | 2.2 ± 0.7 | 2.2 ± 0.5 | 1.8 ± 0.5 | 2 ± 0.9             |

**Fig. 8**

**References:** National Kapodistrian University of Athens, 2nd Department of Radiology, General University Attikon Hospital - Chaidari/GR

Subjective image quality as assessed by two radiologists, revealed a slight improvement in the image scores concerning sharpness, LCR and artifacts in groups 1 and 2 for images
reconstructed with the iDose\textsubscript{4} algorithm compared to FBP, however this improvement was not statistically significant (p>0.05). Radiologists consistently scored better for noise to images obtained with iDose: Image noise was significantly lower for levels 4 (p=0.002, group 1 and p=0.001, group 2) and 6 (p<0.001, groups 1, 2) of iDose\textsubscript{4} compared to FBP. For the first group, the noise reduction resulted in significantly better diagnostic outcome (p= 0.023 and p= 0.013 for L4 and L6 of iDose vs FBP) while for the second group no significant change was observed in the diagnostic confidence among the three reconstructions (p>0.19).

It is also worth mentioning that, in axial mode, reduced dose images reconstructed with FBP received a score of 2.5 (Good to fair diagnostic confidence), which is above the base of 3.

**Images for this section:**

![Table 5. Subjective IQ](image)

<table>
<thead>
<tr>
<th>Group 1 (iDose+spiral)</th>
<th>Noise</th>
<th>Sharpness</th>
<th>LCR</th>
<th>Artifacts</th>
<th>Diagnostic Confidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>FBP</td>
<td>3.2 ± 0.7</td>
<td>3.0 ± 0.6</td>
<td>3.0 ± 0.7</td>
<td>2.6 ± 0.6</td>
<td>3.1 ± 0.7</td>
</tr>
<tr>
<td>L4</td>
<td>2.3 ± 0.6</td>
<td>2.6 ± 0.6</td>
<td>2.5 ± 0.5</td>
<td>2.4 ± 0.6</td>
<td>2.4 ± 0.6</td>
</tr>
<tr>
<td>L6</td>
<td>2.1 ± 0.6</td>
<td>2.5 ± 0.5</td>
<td>2.5 ± 0.5</td>
<td>2.4 ± 0.7</td>
<td>2.2 ± 0.8</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Group 2 (iDose+axial)</th>
<th>Noise</th>
<th>Sharpness</th>
<th>LCR</th>
<th>Artifacts</th>
<th>Diagnostic Confidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>FBP</td>
<td>2.7 ± 0.4</td>
<td>2.5 ± 0.5</td>
<td>2.6 ± 0.4</td>
<td>2.5 ± 0.6</td>
<td>2.5 ± 0.7</td>
</tr>
<tr>
<td>L4</td>
<td>2.1 ± 0.3</td>
<td>2.3 ± 0.4</td>
<td>2.2 ± 0.4</td>
<td>2.4 ± 0.7</td>
<td>2.1 ± 0.9</td>
</tr>
<tr>
<td>L6</td>
<td>1.9 ± 0.4</td>
<td>2.3 ± 0.4</td>
<td>2.0 ± 0.4</td>
<td>2.3 ± 0.7</td>
<td>2.1 ± 0.8</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Group 3 (FBP+spiral)</th>
<th>Noise</th>
<th>Sharpness</th>
<th>LCR</th>
<th>Artifacts</th>
<th>Diagnostic Confidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>FBP</td>
<td>2.5 ± 0.6</td>
<td>2.7 ± 0.6</td>
<td>2.5 ± 0.7</td>
<td>2.4 ± 0.9</td>
<td>2.4 ± 1.0</td>
</tr>
<tr>
<td>L4</td>
<td>2.4 ± 0.4</td>
<td>2.2 ± 0.7</td>
<td>2.2 ± 0.5</td>
<td>1.8 ± 0.5</td>
<td>2 ± 0.9</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Group 4 (FBP+axial)</th>
<th>Noise</th>
<th>Sharpness</th>
<th>LCR</th>
<th>Artifacts</th>
<th>Diagnostic Confidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>FBP</td>
<td>2.4 ± 0.4</td>
<td>2.2 ± 0.7</td>
<td>2.2 ± 0.5</td>
<td>1.8 ± 0.5</td>
<td>2 ± 0.9</td>
</tr>
</tbody>
</table>
Conclusion

This study demonstrated that the application of iDose4 instead of FBP at CCTA is feasible at 64-slice MDCT and that it facilitates radiation dose reduction without compromise of the imaging quality.

Dose reduction of 43% was achieved in retrospective CCTA protocol and 27% in prospective CCTA protocol without impairment of diagnostic confidence. In prospective CCTA protocols reduced dose images were of very good quality (grade ~2) and even those reconstructed with FBP were diagnostically acceptable, thus in this mode additional reduction of exposure settings is feasible. The combination of IR with prospective acquisition has the potential to significantly reduce ED (~2.4 mSv) associated with CCTA and there is strong evidence that ED lower than 2 mSv could be reached.

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References


