ORIGINAL ARTICLE

Effect of low tube kV on radiation dose and image quality in retrospective ECG-gated coronary CT angiography

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KEYWORDS
Coronary; CTA; Low dose; kV; Image quality

Abstract  Introduction: Coronary computed tomography angiography (CCTA) has emerged as a useful diagnostic imaging modality in the assessment of coronary artery disease. However, the potential risks due to exposure to ionizing radiation associated with CCTA have raised concerns. Objectives: CCTA can be done with low dose technique to reduce radiation exposure, without compromise of image quality or diagnostic capabilities. Material and methods: Forty patients referred for CCTA were examined with low kV (100 kV for patients ≤65–61 kg and 80 kV for patients ≤60 kg). The dose length product (DLP) were compared with other group (40 patients) with comparable body weight, scan length and acquisition parameters. The second group was selected from PACS database, for which CCTA was done with standard 120 kV.

Abbreviations: CCTA, coronary computed tomography angiography; PACS, picture archiving and communication system; VR, volume rendering; MPR, multiplanar reformat; MPCR, multiplanar curved reformat; mSv, millisievert; ATCM, automatic tube current modulation; ECTCM, electrocardiographically controlled tube current modulation; BMI, body mass index; kVp, peak kilovoltage

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1. Introduction

With the introduction of 64-slice computed tomography, CCTA has emerged as a useful diagnostic imaging modality for the assessment of coronary artery disease. It is considered appropriate for selected indications (e.g., in patients with a low-to-intermediate pretest probability for obstructive coronary artery disease) (1,2). In addition, CCTA has been proposed to be useful in the rapid evaluation of patients with chest pain in the emergency department (3). With the constantly increasing number of CCTA capable scanners worldwide, the volume of CCTA scans performed is likely to show substantial further increase (4). The clinical usefulness of CCTA for the assessment of coronary artery disease has to be weighed against the radiation exposure of CCTA and the small but potential risk of cancer induction. Many clinicians may still be unfamiliar with the magnitude of radiation exposure that is received during CCTA in daily practice and with the factors that contribute independently to radiation dose. This information is of vital importance for the development of strategies that will allow a reduction of patient exposure to ionizing radiation (5).

1.1. Strategies for reduction of radiation dose

1.1.1. Automatic tube current modulation (ATCM)

Automatic tube current modulation (ATCM) may be defined as a set of techniques that enable automatic adjustment of the tube current in the x-y plane (angular modulation) or along the z-axis (z-axis modulation) according to the size and attenuation characteristics of the body part being scanned and achieve constant CT image quality with lower radiation exposure. Hence, ATCM techniques are analogous to the automatic exposure-control used in conventional radiography (6). Although additional algorithms are available to modulate the tube current online during noncardiac scanning, the adapted tube current usually remains constant for the entire scan range in the cardiac automated exposure-control mode (5).

1.1.2. Electrocardiographically tube current modulation (ECTCM)

Electrocardiographically controlled tube current modulation (ECTCM) has been shown to effectively reduce radiation dose during retrospective electrocardiographically (ECG) gated cardiac spiral CT (7). Because cardiac motion is greatest during systole and least during diastole, diastolic image reconstructions are most likely to provide motion-free data sets. Accordingly, this algorithm restricts the prescribed tube current to a predefined time window during the diastolic phase and decreases tube current in the systolic phase of the cardiac cycle. Because the algorithm increases or decreases tube current prospectively, a regular heart rhythm is required to avoid applying the wrong tube current to the cardiac phase of interest.

1.1.3. Tube voltage

Usually, CCTA is performed using a tube voltage of 120 kV. However, CCTA acquisition with 100-kV tube voltage is also possible and has been suggested as a means to lower radiation dose (7). Reducing tube voltage is a standard procedure in pediatric CT and it has been used in cardiac CT primarily in non-obese patients (body weight \( \leq 85 \) kg or BMI \( \leq 30 \)) owing to increased image noise. In addition to increasing image noise, a lower tube voltage also increases contrast in scans performed with the use of iodinated contrast agents, because iodine absorption is higher at lower tube voltage settings (7–8).

1.1.4. Prospective ECG triggered sequential scan (step and shoot)

This has recently been reintroduced into CCTA. Compared with the conventional retrospective ECG-gated spiral scan technique, which applies radiation during the entire cardiac cycle, radiation is only administered at one predefined time window of the cardiac cycle within the sequential scan mode. The radiation tube is inactive during the remainder of the cardiac cycle, which leads to substantial reductions in dose. However, this scan mode allows minimal or no flexibility in retrospectively choosing different phases of the cardiac cycle for image reconstruction once the data have been acquired (9–10).

1.1.5. Bismuth shielding

This has been shown to reduce radiation dose while still producing diagnostic quality images. Bismuth breast shields have been shown to reduce breast dose by 26.9% to 52.4% in the

<table>
<thead>
<tr>
<th>Heart rate</th>
<th>Dose (mg)</th>
</tr>
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<tbody>
<tr>
<td>55–60</td>
<td>12.5–25</td>
</tr>
<tr>
<td>60–65</td>
<td>25–50</td>
</tr>
<tr>
<td>65–70</td>
<td>50–100</td>
</tr>
<tr>
<td>70–80</td>
<td>100–150</td>
</tr>
<tr>
<td>&gt;80</td>
<td>100–200</td>
</tr>
</tbody>
</table>

Redose with 25–50 mg after 30 min if needed.

<table>
<thead>
<tr>
<th>1st Group</th>
<th>2nd Group</th>
<th>2nd Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>kV</td>
<td>80</td>
<td>100</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>≤60</td>
<td>≤85–61</td>
</tr>
<tr>
<td>Number</td>
<td>6</td>
<td>34</td>
</tr>
<tr>
<td>Scan length (mm)</td>
<td>137 ± 26</td>
<td>135 ± 21</td>
</tr>
<tr>
<td>DLP (mGy-cm)</td>
<td>440 ± 10</td>
<td>635 ± 20</td>
</tr>
</tbody>
</table>

|   | 2 patients in the 1st group subjected to extended scan length to include aorta (Figs. 2 and 3). |
|   | DLP includes doses from bolus tracking + helical cardiac scan. |
adult population depending on the thickness of the shield, they are generally used when scanning women < 50 years of age when breast tissue is included in the range of scanning. Similarly, bismuth breast shields have been shown to reduce breast dose by 29% in pediatric patients (11).

2. Aim of study

Show effect of low kV technique during CCTA on radiation dose, image quality and diagnostic yield.

### Table 3  CT parameters and effect on CT radiation dose.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Relationship to dose&lt;sup&gt;a&lt;/sup&gt;</th>
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<tbody>
<tr>
<td>Tube current</td>
<td>Direct, linear</td>
</tr>
<tr>
<td>Gantry rotation time</td>
<td>Direct, linear</td>
</tr>
<tr>
<td>Kilovoltage</td>
<td>Direct nonlinear</td>
</tr>
<tr>
<td>Pitch</td>
<td>Inverse, linear</td>
</tr>
</tbody>
</table>

<sup>a</sup> Relationship to dose when other variables are held constant.

3. Patients and methods

This study included two groups underwent CCTA with different kV techniques. This 1st group included 40 patients weighing 85 kg (BMI = 30) or less who underwent CCTA using low kV technique. Given that all other acquisition parameters are fixed, patients weighing ≤ 85–61 kg are examined with 100 kV and patients weighing ≤ 60 kg are examined with 80 kV. Breast shields were not used in this study. Dose length product (DLP) was recorded for each examination. The DLP gives an estimate of the radiation dose and used as a method of comparison with radiation dose produced by standard 120 kV CCTA techniques. An estimate of the effective radiation dose in mSv is obtained by multiplying the DLP by a conversion factor which is 0.017 for chest CT.

All patients were informed about nature and steps of the examination and coached to hold breath properly. 18-gauge catheter is inserted in an antecubital vein. Beta blocker

![Figure 1](image-url) 30 YOM presented with chest pain, referred for CCTA, his body weight was 78 kg. Low dose CCTA shows normal coronaries. (A–C) 3D VR, (D) curved reformat image for LAD artery. Legend: LMA = left main artery, LAD = left anterior descending artery (open block arrow), 1st D = first diagonal, SP = septal perforators (black arrows), LCX = left circumflex, 1st OM = first obtuse marginal, RCA = right coronary artery, PDA = posterior descending artery, PLB = posterolateral branch, CX = crux.
(propranolol or metoprolol) was given to all patients according to baseline heart rate (Table 1).

All patients were examined by 64-slice; GE CT Volume (CTV). CCTA was done with retrospective gating and ECTCM. Scans were limited to cardiac structures only unless there were indications to scan aorta or coronary artery bypass graft (CABG). Scans were performed using the following parameters: 350 ms gantry rotation time, detector collimation $64 \times 0.625$ mm, maximum current of $800$ mA and craniocaudal direction. Tube kV was 100 for patients $\leq 65$–61 kg and $80$ kV for patients $\leq 60$ kg. Non-ionic contrast media (Xenetix 350 or iopamidol 370), $1$–$2$ ml/kg was injected using a dual-head power injector. Maximum enhancement at aortic root was determined using bolus tracking technique with $15$ ml contrast followed by $20$ ml saline chaser at $5$ ml/s injection rate. The helical scan was acquired with $60$–$100$ ml contrast and $30$–$50$ ml saline chaser at $5$ ml/s rate.

Reconstructions of the raw data were performed at different percentage of cardiac cycle by $10\%$ from $0\%$ to $90\%$ of the R-R interval. All images were transferred to a workstation (GE Advantage workstation 4.3) for 3D VR, 2D MPR and 2D CMPR.

The 2nd group consists of 40 patients selected from PCAS database, for whom regular 120 kV CCTA were performed. Apart from kV, all other factors were comparable with that in group 1, e.g. body weight, scan length, heart rate and acquisition parameters. The DLP of these scans were also recorded.

4. Results

The 1st group in this study consists of 40 patients, 34 weigh $\leq 65$–61 kg, six patients $\leq 60$ kg, they were 26 males and 14 females, their age ranged from 11 to 85 years. They underwent low kV CCTA, 100 and $80$ kV for patients $\leq 65$–61 kg and $\leq 60$ kg, respectively. The scan range was $137 \pm 26$ mm and the DLP range was $635 \pm 25$ mGy-cm and $440 \pm 15$ mGy-cm, respectively.

The 2nd group consists of 40 patients weighing $\leq 85$ kg, underwent CCTA with regular 120 kV technique. They were 28 males and 12 females, age ranged from 10 to 87 years. Their

![Figure 2](image-url) 65 YOM with dilated ascending aorta, referred for assessment of coronary arteries, his weight was 85 kg. Low kV CCTA. (A) 3D VR shows dilated ascending aorta but normal aortic root and coronaries. (B) Curved reformat image shows incidental finding of intramyocardial course of LAD mid-segment = D2 (arrow). (C) CCTA with regular 120 kV in another patient weighs 84 kg shows intramyocardial course of D2 segment. Image quality has no appreciable difference.
body weight, scan length and heart rate were comparable to patients’ characteristics in 1st group. The scan range was 135 ± 21 mm and DLP was 1120 ± 75 mGy-cm (Table 2).

The DLP was markedly reduced compared to regular 120 kV scan. Patients subjected to 100 and 80 kV scans show about 40.7% and 58.9% reduction in DLP compared to group B.

5. Discussion

There are several reasons why CT radiation dose is potentially high: (1) there is no dose penalty for relatively high radiation dose examinations; (2) CT doses are intrinsically high radiation dose examinations; (3) there are “hidden” dose penalties that occur with CT; and (4) there is no binding regulation for CT practice (11).

The dose length product (DLP) is the CT Dose Index (CTDIvol) multiplied by the scan length (slice thickness × number of slices) in centimeters. It should be noted that the DLP is independent of what is actually scanned. In other words, the reported DLP is the same whether a 10-lb infant or a 100-lb teenager is scanned if the scan length and other scan parameters are the same (12). An estimate for effective radiation dose derived from the DLP requires multiplying DLP by a conversion factor for the body part imaged. For cardiac CT; a factor of 0.017 for chest imaging is most commonly applied.

Most efforts at reducing dose through selectable parameters are focused on tube current (including using tube current modulation) and kVp (Table 3). Additional strategies include minimizing multiphase scanning, limiting the range of coverage, and using in-plane shielding. As always, optional imaging

Figure 3  11 YOB, 39 kg, has bradycardia, CCTA with wide scan length to include aorta. (A–C) 2D curved reformat for LAD, LCX and RCA, respectively, show normal coronaries. (D) 3D VR for coronaries and aorta show mild fusiform segmental dilatation of DA (curved arrows) and motion “breathing” artifacts (arrows).
modalities that do not expose the individual to radiation or provide additional substantive risks, such as magnetic resonance imaging or sonography, should be considered (12).

In this study, we tried to comply with ALARA concept (as low as reasonably achievable) by reducing the radiation dose to slim patients. Certain steps related to the scan and acquisition is followed. Regarding scanning protocols, (1) the heart rate was controlled with beta blockers and targeted at ≤ 65 beat/s, (2) the scan length was limited to the heart unless indicated; (3) patient was coached to hold breath properly to avoid repeat series. Regarding acquisition protocol, ECTCM, the fastest gantry rotation (0.350 s) was used in all patients which are well known methods to reduce radiation dose. The pitch was similar in all patients (0.22–0.24:1). The tube kV was also reduced to allow considerable reduction in radiation dose. In this study, use of 100 kV for patients ≤ 85–61 kg and 80 kV for patients ≤ 60 kV resulted in about 40% and 60% reduction of DLP, respectively, compared with regular 120 kV protocols in patients with comparable body, scan and acquisition parameters. This approach of dose reduction was also described by Stephan et al. (13). They mentioned a common approach to reduce radiation dose by lowering tube current and voltage. The X-ray exposure changes linearly with tube current (and scan length), but it changes with square of tube voltage. Thus decreasing X-ray tube peak voltage from 120 to 80 kVp can result in a 70% reduction of radiation dose for a given tube current. Other techniques like in-plane bismuth shields were not used in our study; however, it has been shown that shields can reduce breast dose by 26.9–52.4% in the adult population depending on the thickness of the shield (14).

In our study, the image quality produced with low kV was sufficient for diagnostic purposes. The 2D and 3D reformatted images show excellent quality compared to standard 120 kV protocols without appreciable negative effect (Figs. 1–5). The image quality can further be improved by using noise reduction filters at post-processing. This result was also described by Pflederer et al. (15) who stated that; the use of lower tube voltage leads to significant reduction in radiation exposure in noninvasive coronary CT angiography and the image quality in non-obese patients is not negatively influenced.

Figure 4  55 YOF, 82 kg presented with chest pain, CCTA using 100 kV (A) Curved reformat image for LAD shows eccentric hard plaque without appreciable stenosis affects proximal segment (D1). (B) Coronal oblique thick slab shows incidental finding of small ASD. Legend: ASD = atrial septal defect, LA = left atrium, LV = left ventricle, RA = right atrium, CS = coronary sinus.

Figure 5  34 YOM complains of recurrent chest pain weighs 74 kg examined with 100 kV CCTA. (A) 3D VR shows coronary artery ectasia (CAE) of RCA mid-segment (R2) and LAD proximal segment (D1). (B) 2D reformat with vessel analysis shows CAE of R2 segment.
6. Conclusion

It is important to keep awareness of radiation exposure in radiologists and radiographers foremost in mind for every patient. Try to reduce kVp whenever possible to 80 or 100 kVp to reduce exposure significantly. Best image quality is not always necessary while diagnostic image quality is more important.

References


