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# Prospective ECG-triggering Coronary CT Angiography (CCTA): How Safe is this Procedure?

**Akmal Sabarudin***

*Diagnostic Imaging & Radiotherapy Programme, School of Diagnostic and Applied Health Sciences, Faculty of Health Sciences, University Kebangsaan Malaysia, 50300, Kuala Lumpur, Malaysia*

***Corresponding author:** Dr. Akmal Sabarudin, Diagnostic Imaging & Radiotherapy Programme, School of Diagnostic and Applied Health Sciences, Faculty of Health Sciences, University Kebangsaan Malaysia, 50300, Kuala Lumpur, Malaysia, Tel: 603-9289 7641; Fax: 603-2692 9032; **E- mail:** akmal.sabarudin@ukm.edu.my

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**Abstract**

With the rapid development of CT technology, the procedure of Coronary CT Angiography (CCTA) has been increasingly used and widely available for the diagnosis of Coronary Artery Disease (CAD). Other than having its advantages to improve the sensitivity and specificity in the detection of CAD, CCTA also associated with high radiation dose. Several dose-reduction strategies have been introduced to reduce radiation dose during CT procedure. However, one of the technique, namely prospective ECG-triggering CCTA provides tremendous radiation dose reduction to patient. Therefore, this article provides information on the prospective ECG-triggering technique and how it can further reduce the radiation dose to patient.

**Keywords:** Coronary CT angiography; Coronary artery disease; Electro Cardiogram (ECG)

## Prospective ECG-triggering Coronary CT Angiography (CCTA): How safe is this procedure?

Over the last fifteen years, tremendous developments have taken place in the CT technology which allows the CT scanner to produce images of the coronary artery lumen and wall in order to provide analysis on severity and characteristics of coronary artery disease has definitely made CCTA a reliable non-invasive diagnostic tool in coronary artery imaging. This article is written to provide information about CCTA scanning techniques, radiation dose associated with CCTA procedure and how prospective ECG-triggering can further reduce the radiation dose to patient.

The acquisition of the dataset for CCTA consists of three steps including topogram, determination for the adequate contrast enhancement of CCTA and the image acquisition for the entire coronary artery tree were made completed with the contrast enhancement setting either using bolus tracking or the test bolus techniques. The scan is acquired in a single breath hold during comfortable inspiration and starts with the injection of a contrast agent with a high concentration of iodine (300–400 mg/mL) at a high flow rate (4–6 mL/s). The total volume of contrast agent depends on the scan length, but typically 60–80 mL is injected, followed by a saline flush (40–70 mL at 4–6 mL/s). The actual CT scan starts after the delay is calculated as the contrast material transit time [1].

There are two techniques in CCTA procedures namely prospective ECG-triggering and retrospective ECG-gating. Both prospective ECG-triggering and retrospective ECG-gating techniques are characterized based on its scanning mode, sequential and helical, respectively. In sequential or known as step-and-shoot scanning mode, a cross-sectional image is produced by acquiring a series of axial slices of the body from different angular positions while the X-ray tube and detector rotate 360° around the patient with the table being stationary. The image is then reconstructed from the resulting projection data which is like merging several contiguous stacks of partial cardiac images until a complete cardiac image is acquired consists of the entire cardiac length within the desired scanned range. However, if the patient moves during the acquisition, the data obtained from different angular positions are no longer consistent and stair-step artifact occurs resulting image degradations and may be of limited diagnostic value [2].

On the other hand, helical or spiral scanning mode uses a different scanning principle. Unlike the sequential CT, this mode allows table to move continuously through the gantry in the z-direction while the X-ray tube rotates 360° around the patient. The X-ray traces a spiral path around the patient and produces volume data. The table movement in the z-direction during the data acquisition will generate inconsistent datasets, causing reconstructed images being degraded by the artefacts. Thus, some special reconstruction algorithms using the interpolation principles to generate planar set of data for each table position producing artefact-free images [2]. Thus, it is possible to reconstruct individual slices from a large data volume by overlapping reconstructions as often as required.

### Radiation dose issue

Although rapid developments in CT technology have led to improve the sensitivity and specificity of CCTA procedure in the detection of Coronary Artery Disease (CAD) in both image quality and diagnostic value, CCTA runs the potential risk of high radiation dose [3,4]. Previous literature has shown that radiation dose increases with increasing detector rows in CT due to narrow detector collimations and long anatomic coverage [5]. In fact, it is generally agreed that CT is an imaging modality with the highest radiation dose of all radiological examinations, as it contributes up to 70 per cent radiation dose of all radiological examinations [6]. Previous research estimated that CT scan causes 800 cancers in woman and 1300 in man per year in the United Kingdom [7]. Moreover, in the United States, approximately 500 out of 600,000 children less than 15 years old who are estimated to undergo CT procedure each year will die of cancer [8]. Moreover, the radiation risks associated with CCTA have raised serious concerns in the literature and many researchers agreed on that there is potential risk of radiation-induced malignancy resulting from CCTA [3,9]. In fact, many researchers were questioning: Does utilization of CCTA lead to the greatest benefit and is the risk of radiation greater than the benefit expected from the CT examinations? [3,10].

Therefore, several dose-saving strategies have been introduced to deal with radiation dose issues, and these techniques include anatomical-based tube current modulation [11], ECG-controlled tube current modulation [12], tube voltage reduction [13], iterative reconstruction algorithm software [14], a high-pitch scanning [15] and prospective ECG-triggered CCTA [16,17]. This article is written to provide information about prospective ECG-triggered CCTA technique which is one of the strategies that could be used to further reduce the radiation dose to patient during CCTA procedure.

## Prospectively ECG-triggered coronary CT angiography

Prospectively ECG-triggered technique is a low-radiation dose scanning method using sequential mode to acquire axial images and an incrementally moving table to cover the heart with minimal overlap of axial slices. This technique in cardiac CT is not new and it recognizes that CT image synchronization with heart diastolic phase was optimal for heart imaging. However, the results were not being achieved when the patient heart rate increases. Unlike the principle of helical continuous scanning in retrospective ECG gating, the principle of data acquisition in this technique takes place only in the selected cardiac phase (diastolic) by selectively turning on the X-ray tube when triggered by the ECG signal. The X-ray tube is remained off for most of the scanning period especially other than diastolic phase in cardiac cycle (Figure 1) [18]. Moreover, during the image acquisition, the table is stationary and then moves to the next position for another scan initiated by the subsequent cardiac cycle (diastolic phase). This results lead to a significant reduction in radiation dose [19]. It has been widely reported that prospective ECG-triggering protocol produces low radiation dose with the effective dose ranging from 3.8 to 6.8 mSv which was significantly lower than that of conventional CCTA method, retrospective ECG-gating technique. This dose reduction ranging from 76% to 83% [17,20].

In 64-slice scanner system, the scan is prescribed by using 3 to 5 incremental of 64 × 0.625 mm (40 mm) image groups which requires up to 4 incremental table translations of 35 mm allowing for 5 mm of overlap. The minimum interscan delay is approximately between 0.6 and 1.0 second which normally requires skipping a cardiac cycle between data acquisitions which results in one image acquisition per 2 cardiac cycles [19]. However, the process will be faster with larger detectors (128-, 256- or 320-slice CT) being used. The detector width determines the number of steps/scans to cover the entire heart and complete the examination. For instance, the dual-source 64-slice CT has a narrower detector array (32 × 2 × 0.6 mm = 38.4 mm per acquisition); thus, it takes more incremental steps (normally 4-5 cardiac cycles) to cover the heart and complete an examination than with the 320-row system (320 × 0.5 mm = 160 mm) which covers the heart in a single acquisition [21].

Prospectively ECG-triggered technique has a limited number of cardiac phases available for reconstruction. Therefore, mid-diastolic phase (75% of R-R interval) was normally selected for data acquisition for all subjects. In addition, by using add-on 'padding' will allow more cardiac phases for reconstruction. Padding technique is described as prolonging the acquisition window in order to produce consistent image quality although scanning a patient with minor heart rate variations (more than ± 5 b.p.m). Although padding can be described as widening the acquisition window, it is actually turns the x-ray tube on before and after the minimum or actual acquisition time (milliseconds) required. Available padding options with current software ranges from 0 to 200 milliseconds. However, radiation dose will definitely increase with application of padding window due to expense of radiation exposure on the particular windows phase [19].

In terms of diagnostic quality and accuracy, prospective ECG-triggering CCTA was proven to have high sensitivity (>89.3%), specificity (>90.5%), positive predictive value (>89.8%), negative predictive value (>90%) and accuracy (>92.3%) in the diagnosis of CAD from a systematic review based on 23 selected studies using prospective ECG-triggering [22].

The main limitations of prospective ECG triggering technique is unavailability of producing cardiac functional analysis due to limited access of the cardiac cycle during data acquisition. The cardiac functional analysis can be provided with multiple phases of cardiac scanning using helical scanning mode. If the clinical scenario or referring physician requires information about cardiac function, then retrospective gating must be undertaken. Heart rate variability is another limitation for the prospective ECG triggered technique. Heart rate variability of > 5 b.p.m. is considered not applicable for prospective ECG-triggering with scanner system which is not equipped with 'padding window' software application

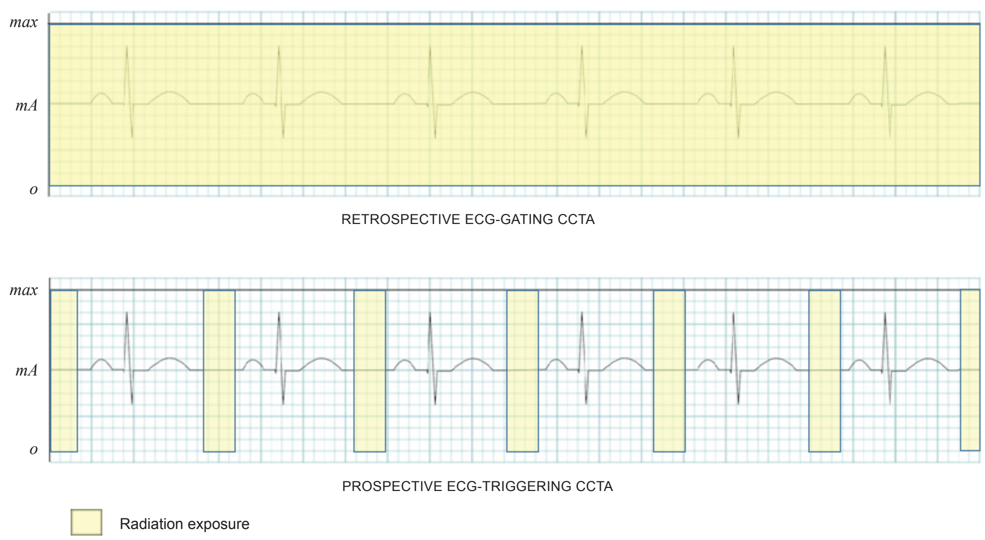


**Figure 1:** Variations in CCTA scanning techniques produced different radiation dose. In standard retrospective gating, the tube current is constantly 'on' throughout the acquisition produces high radiation dose while in prospective ECG-triggering, the exposure is 'on' at the selective cardiac phase (diastolic phase) for a short period resulting low radiation dose production.

<table>
<tr><th colspan="2">Prospective ECG-triggering CCTA</th></tr>
<tr><th>Advantages</th><th>Disadvantages</th></tr>
<tr><td>Low radiation dose</td><td>High and irregular heart rate</td></tr>
<tr><td>High diagnostic accuracy</td><td>Limited cardiac cycle during data acquisition</td></tr>
<tr><td rowspan="2">Good image quality [17]</td><td>No cardiac functional analysis</td></tr>
<tr><td>Longer scanning time</td></tr>
<tr><th colspan="2">Retrospective ECG-gating CCTA</th></tr>
<tr><th>Advantages</th><th>Disadvantages</th></tr>
<tr><td>High diagnostic accuracy</td><td>High radiation dose</td></tr>
<tr><td>Good image quality</td><td rowspan="4">High and irregular heart rate*</td></tr>
<tr><td>Availability of cardiac functional analysis</td></tr>
<tr><td>Multiple cardiac cycle available during data acquisition</td></tr>
<tr><td>Shorter scanning time</td></tr>
</table>

*Depending on types and generations of multidetector CT scanner

**Table 1:** Summary of advantages and disadvantages of prospective ECG-triggering versus retrospective ECG-gating CCTA

especially in 64-slice scanner [19]. A summary of advantages and disadvantages of prospective ECG-triggering versus retrospective ECG-gating CCTA is shown in Table 1.

In conclusion, coronary CT angiography with prospective ECG-triggered technique has proven to produce low radiation dose with high diagnostic quality and accuracy in the diagnosis of CAD. With low effective dose from 3.8 mSv, it is believed that prospective ECG-triggering CCTA is a safe procedure to be performed in radiological investigation procedures as a screening tool for the assessment of coronary arteries.

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