Radiation dose in coronary CT angiography associated with prospective ECG-triggering technique: Comparisons with different CT generations

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Abstract

A retrospective analysis was performed in patients undergoing prospective ECG-triggered coronary CT angiography (CCTA) with single-source 64-slice CT (SSCT), dual-source 64-slice CT (DSCT), dual-source 128-slice CT and 320-slice CT with the aim of comparing radiation dose associated with different CT generations. A total of 164 patients undergoing prospective ECG-triggered CCTA with different types of CT scanners were studied with the mean effective dose estimated 6.8 ± 3.2 mSv, 4.2 ± 1.9 mSv, 4.1 ± 0.6 mSv, and 3.8 ± 1.4 mSv, corresponding to 128-slice DSCT, 64-slice DSCT, 64-slice SSCT and 320-slice CT scanners. A positive relationship was found between effective dose and body mass index (BMI) in this study. Low-radiation dose is achieved in prospective ECG-triggered CCTA, regardless of the CT scanner generation. BMI is identified as the major factor that has a direct impact on the effective dose associated with prospective ECG-triggered CCTA.

Keywords: prospective ECG-triggering, coronary CT angiography, effective dose, CT generations

Introduction

Coronary computed tomography angiography (CCTA) has been increasingly used in the diagnosis of coronary artery disease (CAD), thanks to its non-invasiveness, rapid acquisition of high resolution images and high diagnostic accuracy [1, 2]. With rapid improvements in spatial and temporal resolution, CCTA not only visualises coronary anatomy and characterises plaque components, but also allows for quantitative analysis of coronary stenosis [3-7]. The rapidly increasing multidetector CT (MDCT) scanners have led to the increase of CCTA examinations worldwide [8]. However, high-radiation dose resulting from CCTA raises a major concern, as radiation-induced cancer is not negligible [4, 8, 9].

Previous studies have reported that CCTA with use of retrospective electrocardiogram (ECG)-gating technique results in very high effective dose, which ranged from 13.4 mSv to 31.4 mSv [5, 10-12]. However, several dose-saving strategies have been introduced in the retrospective ECG-gated CCTA to deal with radiation dose issues, and these techniques include anatomy-based tube current modulation [13, 14], ECG-controlled tube current modulation [15-17], tube voltage reduction [18, 19] and high-pitch scanning [20, 21].

Apart from these dose-saving strategies, prospective ECG-triggering technique was recently introduced in CCTA examination with resultant very low dose when compared to conventional retrospective ECG-triggering protocol [5, 12, 22]. Prospective ECG-triggering scan (also called step-and-shoot mode) is triggered by the ECG signal and x-ray tube is only turned on at the selected cardiac phase (diastolic), and turned off during the rest of the cardiac cycle. Consequently, this results in a significant reduction of radiation dose during prospective ECG-triggering CCTA. In contrast, for the retrospective gating technique, the x-ray tube is turned on throughout the entire cardiac cycle, leading to higher radiation dose than the prospective triggering protocol [23].

Because of the promising low-dose results, many studies have been conducted with recent CT models ranging from 64-slice to 320-slice scanners to compare prospective triggering and retrospective ECG-gating protocols with regard to the dose reduction, image quality and diagnostic value in CCTA [7, 22, 24, 25]. Despite satisfactory results in prospective ECG-triggered protocol, very few studies have been conducted to compare the radiation dose between different CT generations with use of prospective triggering [26, 27]. Therefore, the aim of study was to compare the radiation dose associated with different multislice CT generations that is done using prospective ECG-triggering technique, based on a retrospective analysis of the patients undergoing CCTA.

Materials and methods

Three hospitals in Klang Valley, Malaysia and one major public hospital in Perth, Western Australia were selected for this study to determine radiation dose exposure to patients in routine CCTA procedures over 6 months (July 2011-January 2012). A retrospective data analysis was performed in all patients undergoing prospective ECG-triggered CCTA with different generations of MDCT scanners. All patients were referred for CCTA due to suspected or known CAD. Patients scanned with retrospective ECG-gated protocol, for other cardiovascular diseases such as pulmonary embolism or coronary artery bypass grafts were excluded from this study. The data were collected and recorded from each hospital independently.

Coronary CT angiography protocols

The study patients were divided into four groups based on CT scanner generations used. There were four different CT scanners from various manufacturers used in the study, namely single-source 64-slice CT (SSCT) (Brilliance 64, Philips Healthcare, USA), dual-source 64-

slice CT (DSCT) (Somatom Definition, Siemens Healthcare, Germany), dual-source 128-slice CT (Somatom Definition Flash, Siemens Healthcare, Germany) and 320-slice CT (Aquilion ONE, Toshiba Medical System, Japan). Table 1 lists the details of CCTA scanning protocols corresponding to different generations of CT scanners, and patient characteristics. The tube current (mA) was selected manually depending on the availability of the scanner (Table 1). Therefore, tube current modulation was not used in this study.

All scan protocols covered from the level of tracheal bifurcation to the diaphragm and a non-ionic contrast media between 60 and 85 ml was administered with a flow rate from 4.5 to 6.0 ml/s in all study groups. A bolus tracking technique was used in all studies to ensure optimal coronary enhancement. The parameters of CT volume dose index ($CTDI_{vol}$) and dose length product (DLP) values were obtained from the scans. Effective dose was derived from the product of DLP and a conversion coefficient of 0.017 $mSv \cdot mGy^{-1} \cdot cm^{-1}$ was used for the chest region [28].

Statistical analysis

Descriptive data were presented as mean ± standard deviation. Data analysis was performed by using SPSS version 19.0 (SPSS V19.0, Chicago, USA). A p value of less than 0.05 was considered statistical significance. Pearson correlation was used to test the relation between radiation dose and body mass index (BMI) in each group. Analysis of variance (ANOVA) test was also used for multifactorial mean comparisons.

Results

A total of 164 patients (98 males, 66 females) undergoing a prospective ECG-triggered CCTA procedure were included in the analysis. Demographic data of the study and radiation dose information are presented in Table 1.

The mean effective doses for each CT scanner group are presented in Figure 1. The results show that the highest effective dose was estimated at 6.8 ± 3.2 mSv in patients scanned with 128-slice DSCT, followed by 4.2 ± 1.9 mSv with 64-slice DSCT and 4.1 ± 0.6 mSv with 64-slice SSCT. Effective dose estimated in 320-slice CT was 3.8 ± 1.4 mSv, which is the lowest among the groups. There was a significant difference in the mean effective dose in patients scanned with 128-slice DSCT when compared to the other groups ($p<0.05$). However, no significant differences were found in the mean effective doses between 64-slice (SSCT and DSCT) and 320-slice CT groups ($p=0.71$).

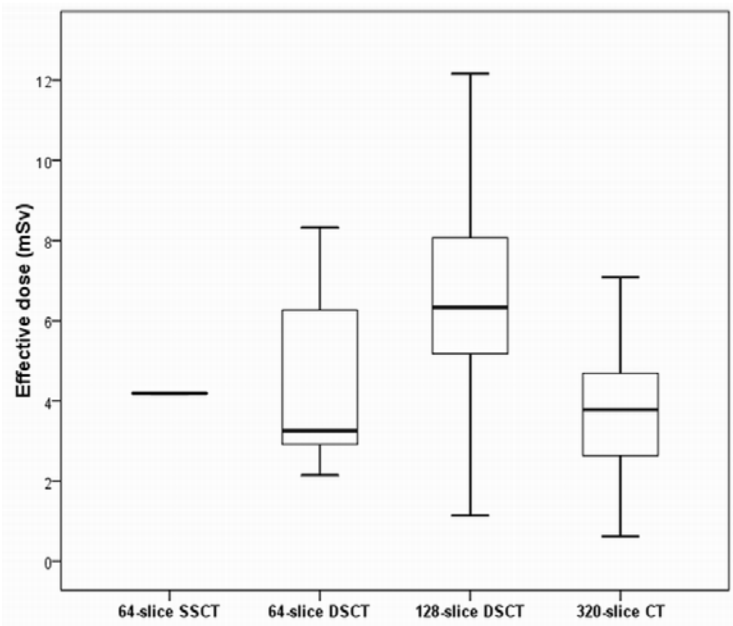

Figure 1: Box plot shows the mean effective dose reported in the studies with use of 64-slice SSCT, 64-slice DSCT, 128-slice DSCT and 320-slice CT. It shows that effective dose in 128-slice DSCT is the highest amongst all of four groups. Also, there is a very small range of dose distribution in 64-slice SSCT group. The box indicates the first to third quartiles, the line in the box indicates median quartile, and whiskers indicate the minimum and maximum values.

The effective dose in males was slightly higher than that in females for 64-slice SSCT (4.1 mSv versus 4.0 mSv), 64-slice DSCT (4.4 mSv versus 4.1 mSv), 128-slice DSCT (6.9 mSv versus 6.6 mSv) and 320-slice CT (3.8 mSv versus 3.7 mSv). However, there was no significant difference in effective dose between males and females in all study groups (p= 0.07, 0.27, 0.38 and 0.19 corresponding to 64-slice SSCT, 64-slice DSCT, 128-slice DSCT and 320 slice CT group, respectively).

Analysis of the relation between effective dose and BMI shows a significantly positive relationship (Figures 2-5) in all groups with a Pearson correlation factor at r=0.6, r= 0.8, r= 0.4 and r=0.7, corresponding to 64-slice SSCT, 64-slice DSCT, 128-slice DSCT and 320-slice CT groups, respectively.

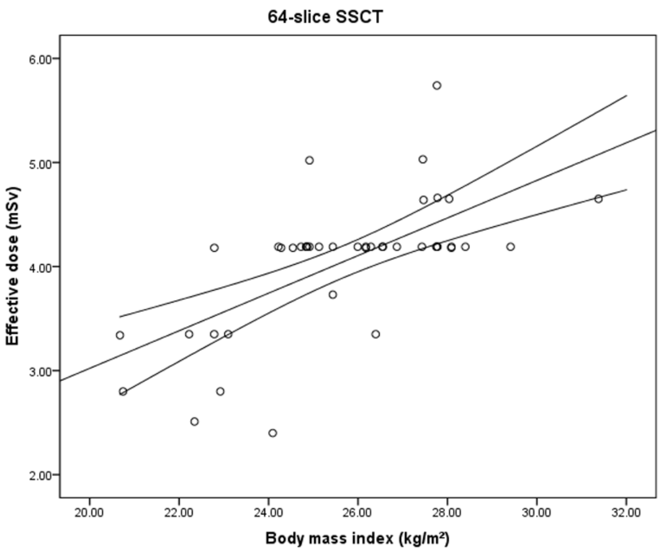

Figure 2: Correlation graph analysis of effective dose depending on body mass index (BMI) for 64-slice SSCT; r = 0.6.

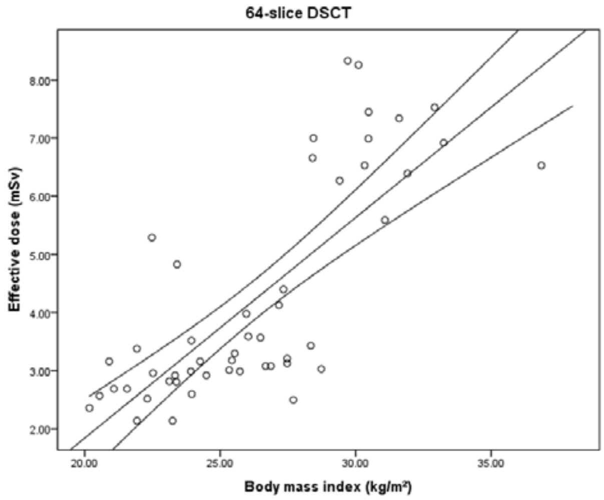

Figure 3. Correlation graph analysis of effective dose depending on body mass index (BMI) for 64-slice DSCT; r = 0.8.

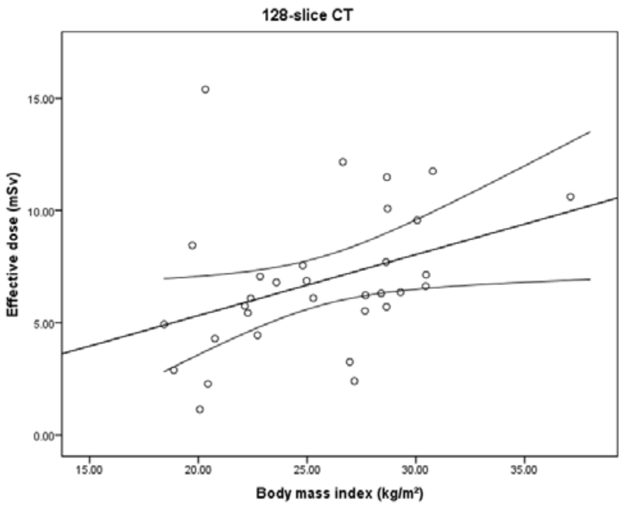

Figure 4: Correlation graph analysis of effective dose depending on body mass index (BMI) for 128-slice DSCT; r = 0.4.

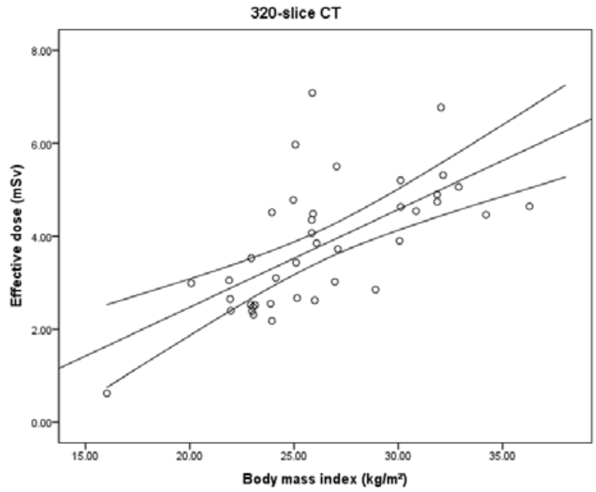

Figure 5: Correlation graph analysis of effective dose depending on body mass index (BMI) for 320-slice CT; r = 0.7.

The effective dose was also compared between 100 kVp and 120 kVp protocols in three groups using 64-slice DSCT, 128-slice DSCT and 320-slice CT. The results show that the differences in effective dose between 100 kVp and 120 kVp protocols are significant in all groups. The mean effective doses were estimated with 3.0 ± 0.5 mSv and 6.6 ± 1.1 mSv in 64-slice DSCT; 5.3 ± 2.1 mSv and 8.0 ± 3.4 mSv in 128-slice DSCT; and 2.8 ± 1.0 mSv and 4.5 ± 1.2 mSv in 320-slice CT corresponding to 100 and 120 kVp respectively. However, the comparison was not performed in 64-slice SSCT group since 100 kVp was not available in the system.

Discussion

This study highlights two important findings in radiation dose associated with prospective ECG-triggered CCTA. First, low-radiation dose can be achieved in CCTA between different generations of CT scanners with the application of prospective ECG-triggering protocol. Second, BMI affects the radiation dose significantly. Hence, in clinical practice, by combining the body weight-adapted tube voltage (such as 100 kVp for BMI <25kg/m^2) with prospective ECG-triggered CCTA, further reduction of effective dose can be achieved with diagnostic image quality.

This comparative study was performed at four different clinical centres where coronary CT angiography was performed using different types of MDCT scanners. Common parameters that affect radiation dose associated with CCTA include tube voltage (kVp), tube current (mA) and pitch value. Since this study was performed with prospective ECG-triggering, the pitch was selected as 1.0 during the CT scans. BMI is another main factor that needs to be considered during CCTA as the kVp and mA for most of the clinical centres in this study are adjusted based on the patient's BMI, thus, it has a direct impact on radiation dose and image quality due to the wide ranges of kVp or mA selections. Despite different clinical sites were included, the same scanning protocol was used among these centres, thus this enabled a comparative analysis of radiation dose from different generations of MDCT scanners.

Patients with BMI < 25 kg/m^2 was scanned with 100 kVp protocol, while a patient with BMI > 25 kg/m2, a tube voltage of 120 kVp was applied. Although the 100 kVp protocol was not available with the 64-slice SSCT, the results were not significantly affected due to a small number of patients (n=11) having BMI less than 25 kg/m^2 in this cohort. Previous studies have reported that effective dose in 100 kVp was significantly lower than that in 120 kVp which patients were classified into these two groups (100- and 120-kVp) based on their BMI [24, 29, 30]. Our analysis is consistent with these reports as a significant reduction of effective dose was achieved in the lower kVp groups.

It has been widely reported that prospective ECG-triggering protocol reduces radiation dose significantly compared to the conventional retrospective ECG-gating technique, with a dose reduction ranging from 76% to 83% [5, 11, 12]. Our results are in line with previous reports. The effective dose of prospective ECG-triggered CCTA was estimated between 3.8 mSv and 6.8 mSv, which correspond to dose reduction between 63% and 82% when compared to effective dose in retrospective ECG-gating from previous studies [5, 11, 12]. In addition, low-radiation dose recorded in our study was found to be similar to that of invasive coronary angiography, which ranges from 3.1 mSv to 10.6 mSv [31-33].

Our study showed that mean effective dose estimated from 64-slice CT scanners (DSCT with 4.2 mSv and SSCT with 4.1 mSv) was consistent with previous results, in which effective dose in DSCT ranged from 2.2 to 6.5 mSv [21, 34-37] and in SSCT ranged from 2.8 to 5.7 mSv [5, 12, 27, 38, 39]. Current data also show that there was no significant difference in effective dose between 64-slice DSCT and SSCT ($p=0.97$) with prospective ECG-triggered protocol since sequential mode data acquisition (step-and-shoot) was used in the study. However, studies on 64-slice CT with the application of retrospective ECG-gated CCTA reported that DSCT produces significantly lower radiation dose compared to SSCT in patients with higher heart rate (>70 bpm) due to interchangable pitch mode corresponding to patients' heart rate [40, 41].

The 128-slice DSCT using prospective ECG-triggering technique is associated with a wide range of effective dose, which is significantly higher than the other groups. In comparison with other reports using 128-slice DSCT prospective ECG-triggering technique, the average effective dose in our data is significantly lower than that reported in other studies, which ranges from 1.7 to 14 mSv [42, 43]. The wide range of 128-slice CT effective dose in this study might be caused by the variable scanning protocols such as adding 'padding' windows in patients with high heart rate variability. The padding technique is used to prolonging the acquisition window in order to compensate for heart rate variations with the aim of producing consistent image quality, but at the cost of high radiation dose [23]. However, the average effective dose (6.8 mSv) in our study was found to be higher than that acquired with the high-pitch (up to 3.4) spiral mode reported in some recent studies using 128-slice CT with estimated effective dose of less than 1 mSv [20, 21]. This emphasises the importance of using high-pitch model in cardiac imaging.

Our study shows that there is no significant difference in effective dose between male and female patients. This is different from the previous literature data, since higher effective dose was reported in females (ranges from 16.3 mSv to 18 mSv) than males (ranges from 12 mSv to 15 mSv) when CCTA was performed with retrospective ECG-gating protocol [1, 2, 44]. However, a study conducted on radiation dose comparison reported that breast dose could be reduced up to 76% with the application of prospective ECG-triggered protocol with use of 70-80% exposure window [45]. This is because there is only a small amount of radiation dose absorbed in the breast tissue during prospective ECG-triggered protocol, which leads to a minimal contribution to the total radiation dose.

There are some limitations in this study. First, image quality assessment was not included since this study focused on the dose comparison between different generations of CT scanners, rather than image quality assessment. Another limitation is a small number of cases being included in each study group due to the strict heart rate control applied to all patients undergoing prospective ECG-gating protocol, thus, excluding a large number of patients. Further studies in patients undergoing prospective ECG-triggered CCTA with inclusion of different heart rates should be conducted to explore the resultant radiation dose. Third, calculation of effective dose was based on a conversion coefficient of 0.017 for the chest region, and this could underestimate the effective dose to the patients. Cardiac CT does not examine the whole chest, as coronary CT angiography is to examine the lower chest and upper abdomen, thus this involves irradiating the breast tissue for the majority of the volume. The conversion factor used to calculate effective dose from coronary CT angiography has been upgraded from 0.014 to 0.028, thus, doses from coronary CT angiography could be significantly underestimated due to failure of using a cardiac specific conversion factor in the recent ICRP documentation [46, 47]. A conversion factor of 0.028 would give a better estimation of the effective dose from prospectively ECG-triggered CCTA [46].

In conclusion, low radiation dose can be achieved in low and regular heart rate with prospective ECG-triggering protocol, regardless of the CT scanner generation. Although there is no significant difference in effective dose between genders, BMI is identified as the main factor that significantly affects the radiation dose in prospective ECG-triggered CCTA in our study.

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