Evaluation of radiation dose from coronary CT angiography (CCTA) examination associated with prospective ECG-triggering technique in multidetector 640-slice scanner

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Abstract. In this study we evaluate radiation dose from a prospective ECG-triggered coronary CT angiography (CCTA) examination multidetector 640-slice CT and compares with other establish references. A total of 98 patient subjects were fall into inclusion criteria and related parameters has been recorded and analysed. It was estimated that the effective dose was at 5.23 ± 4.38 mSv (range 1.34 to 20.35 mSv) and it was significantly lower than that stated in the national dose reference level (NDRL) with 57% difference. It is highly recommended that the practice of using prospective ECG-triggering CCTA with low scanning range provides an optimum amount of radiation dose when compared to previous practice.

1. Introduction

Coronary computed tomography angiography (CCTA) is a non-invasive diagnostic tool for detecting coronary artery disease (CAD) that has low radiation exposure on patients compared with conventional angiography [1], [2]. The increasing multidetector CT (MDCT) scanners have led to the increase of CCTA examinations worldwide [3]. With rapid improvements in spatial and temporal resolution, CCTA has demonstrated highly accurate identification of coronary artery characterized and plaque components which is calcified or non-calcified [4]. However, high-radiation dose can produce detrimental effects on the radiosensitive organs, such as the eye lens, pituitary gland, thyroid gland, breast, and skin [5]. Previous studies have reported that CCTA with use of retrospective ECG-triggering technique results in very high radiation dose, which ranged from 13.4 mSv to 31.4 mSv [3], [6]. 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, ECG-controlled tube current, tube voltage reduction and high-pitch scanning [1], [7]. Apart from these dose-saving strategies,
prospective ECG-triggering technique was recently introduced in CCTA examination with resultant very low dose compared to retrospective ECG-triggering technique [6]. 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 and retrospective ECG-triggering protocols with regard to the dose reduction in CCTA [8]. 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 [3]. Therefore, the aim of study was to evaluate radiation dose associated with prospective ECG-triggering technique and to compare with other establish reference.

2. Materials and methods
A retrospective data analysis was performed in all patients undergoing CCTA examination due to suspected or known CAD. A university teaching hospital, UKM Medical Center in KL was selected for this study to determine radiation dose exposure to patients in routine CCTA procedures over 12 months (January to December 2018) since it has been operated. Patients scanned with retrospective ECG-gated protocol, higher heart rate (>70) and pediatric cases were excluded from this study.

2.1. CCTA Acquisition
The CCTA examination was scanning using 640-slice scanner (Aquilion ONE, Toshiba Medical System, Japan) with 320 detector row and 0.5-mm detector elements. Volumetric data with 16cm z-axis coverage were acquire using prospective ECG-triggering technique. ECG-pulsing window with padding was set at 70–80% of the R–R interval were used in patient with a heart rate <65 beats per minute. Patient with higher heart rate was monitored and beta blocker were given.

2.2. Contrast medium administration
Scanning plan was covered from the level of tracheal bifurcation to the diaphragm. Non-ionic contrast medium which is Omnipaque 370mg/mL was used 50–70mL and administrated intravenously at 4.5-5.0 mL/s flow rate followed by 40 mL saline flush at 4.5-5.0 mL/s. Bolus tracking was done manually at the region of interest (ROI) which is left ventricle until contrast medium filled it up without using any baseline threshold Hounsfield Unit (HU) and with series of low dose monitoring scan. The volume scan was started right away and scan the entire heart.

2.3. Radiation Dose
Dose information such as CT volume dose index (CTDIvol) and Dose Length Product (DLP) values were obtained from the console and recorded in the standardized form. The estimated effective dose was derived from the product of DLP and a conversion coefficient factor of 0.014 mSv·mGy·cm-1 was used for the chest region (Huda et al., 2008). The values were compared with other establish data either used of retrospective or prospective ECG triggering scanning method

2.4. 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. T-test was used for mean comparison and analysis of variance (ANOVA) test was also used for multifactorial mean comparisons.

3. Results
A total of 98 patients (56 males, 42 females) undergoing CCTA procedure were included in the analysis. The mean age was 51.57 ± 10.84 for male and 49.29 ±12.19 for female. Demographic data of patient and parameter in this study are presented in Table 1. Each of these examinations was divided into 2 subgroups according to the patient gender which is male and female. Radiation dose of CCTA examination represent as CT dose index (CTDI), dose length product (DLP) and effective dose. All the results express as mean and standard deviation.
In general, the results of CTDi state that 23.56 ± 19.61 mGy, while the results of DLP state that 373.75 ± 313.28 mGy.cm. Effective dose calculated by using product of DLP and a conversion coefficient factor of 0.014 mSv·mGy−1·cm−1 was 5.23 ± 4.38 mSv. The NDRL set by MOH Malaysia for CCTA is 11.8 mGy for CTDi and 870 mGy.cm for DLP while effective dose was 12.18 mSv. Comparison between results of this study with NDRL show that effective dose was significantly lower than stated in the NDRL with 57% difference.

In gender comparisons, both male and female show no significant differences because the p-values were more than 0.05 in both CTDi and DLP. The effective dose in male patients was higher than female patients in CCTA examinations with 5.49 ± 4.69 mSv versus 3.6 ± 2.75 mSv, respectively. However, both genders show lower effective dose compared to that in NDRL at 55% difference in male and 60% difference in female.

Two scanning range that used in this study were 140 mm and 160 mm to cover the entire length of cardiac region. The CTDi of 140 mm and 160 mm was 18.53 ± 14.03 mGy versus 26.35 ± 19.45 mGy while DLP of 140 mm and 160 mm was 259.30 ± 196.38 mGy versus 421.38 ± 311.14 mGy. Both comparisons show lower effective dose in 140 mm compared to 160 mm scanning range by 40% different, however these differences were not significant because of p-value more than 0.05. Both 140 mm and 160 mm scanning range, show the lower effective compared to NDRL by 60% and 52% difference respectively. Overall results presented in Table 2.

**Table 1. Demographic data and parameter used.**

| Parameter                  | Male          | Female        |
|----------------------------|---------------|---------------|
| Gender (%)                 | 57            | 43            |
| Age (Mean & SD)            | 51.57 ± 10.84 | 49.29 ± 12.19 |
| Heart rate (bpm)           | <65           | <65           |
| Collimation (mm)           | 320 x 0.5     | 320 x 0.5     |
| Slice thickness & interval (mm) | 0.5 & 1.0   | 0.5 & 1.0     |
| Pitch                      | 0             | 0             |
| Rotation time (ms)         | 350           | 350           |
| Tube voltage(kv)           | 120           | 120           |
| Tube current(mA)           | <600          | <600          |
| Tube current time(mAs)     | 300-500       | 300-500       |
| Scan time (s)              | <9            | <9            |
| Noise index                | 10            | 10            |
| Dose modulation            | ON            | ON            |
| Kernel                     | FC03          | FC03          |
| Scanning type              | Prospective ECG-triggering | Prospective ECG-triggering |
| Iterative reconstruction   | AIDR          | AIDR          |

**Table 2. Overall results of radiation dose in CCTA examination**

| Examinations | DOSE | CTDi (mGy) | DLP (mGy.cm) | ED (mSv) | P-value |
|--------------|------|------------|--------------|----------|---------|
| **Total**    |      | 23.56 ± 19.61 | 373.75 ± 313.28 | 5.23 ± 4.38 |         |
| **Gender**   |      | 24.72 ± 20.94 | 392.67 ± 335.01 | 5.49 ± 4.69 | CTDi-0.11 |
| Male         |      | 21.94 ± 17.72 | 347.44 ± 282.23 | 4.86 ± 3.95 | DLP-0.11 |
| Female       |      |             |              |          |         |
| **Scanning** |      | 18.53 ± 14.03 | 259.30 ± 196.38 | 3.6 ± 2.75 | CTDi-0.26 |
| range        |      | 26.35 ± 19.45 | 421.38 ± 311.14 | 5.9 ± 4.36 | DLP-0.15 |
4. Discussion
Based on the results, three important findings were highlighted in this study. Firstly, effective dose received from CCTA examination in UKMMC was significantly lower compared to that national dose reference level (NDRL) for CCTA. Secondly, this study showed that by using 640-slice CT technology has the ability to produce lower effective dose compared to other CT generations reported in previous studies. Thirdly, this study proved that, low-radiation dose can be achieved by using proper dose reduction strategy method during CCTA examination.

Effective dose of CCTA in UKMMC reported lower than NDRL due to several factors. The results of this study state 57% difference in dose reduction compare to NDRL. Main factor of lower effective dose in this study because of prospective ECG-triggered was used. Previous study reported that prospective ECG-triggering significantly reduces radiation dose compared to retrospective ECG-triggering, with a dose reduction ranging from 76% to 83% [6]. Similar findings were stated in line with previous reports because prospective ECG-triggering provide sequential scanning with minimum radiation exposure in one gantry rotation time [4]. Prospective ECG-triggering also allow data acquisition only in selected cardiac phase by turning on x-ray tube when ideal ECG signal detected [3] because of that, it produces lower radiation dose significantly. The disadvantage of using prospective ECG-triggering is limited number of reconstruction algorithms thus functional analysis cannot be determined [6]. Other than that, the comparison with the current NDRL exist the argument because the studies of NDRL was done from 2007 to 2009 with data were collected from old version SSCT [9], because of that, recent study using the latest features of CT scanner produces lower radiation dose compare to NDRL. This survey of radiation dose was suggested to be performed constantly in order to monitor CT dose trends for NDRL. This regular revise will help to identify latest features of CT scanner that affecting production of radiation dose and updating recent NDRL.

Using recent CT technology (640-slice MDCT) also contributes to lower effective dose compared to previous study on different CT generations. Comparison with previous studies using different CT generations was presented in Table 3. The reasons of this comparison were to prove that recent features of CT scanner contributed in the reduction of effective dose in CCTA examination. One of the latest features is wide area detector with 16 cm z-axis coverage allowing acquisition of the entire coronary artery tree in one gantry rotation with one heartbeat thus reducing the radiation dose [10]. In line with these statement, this study used volumetric scan to allow image acquisition of the entire heart within a single gantry rotation in one heartbeat. In fact, no pitch was used due to sequential scanning mode was activated, thus, no overlapping exposures which leads to the shorter scanning time to the patient [2]. This study also stated lower effective dose compared to previous CT scanner generation because of regularity of heart rate rhythm. These wide area of detector provides lower radiation exposure in patients with controlled heart rate (<65 bpm) [1], [10]. In this case, the patients’ recruitment process was very strict which all patients should have either a consistent and low heart rate (<65bpm) or controlled with beta-blocker prior to the scanning procedure[1], [2].

Thirdly, using proper dose reduction strategy also contributed to low radiation dose. Variety of dose reduction strategy was used in this study that influencing the lower effective dose. First strategy that was to minimize scanning range that used during CCTA examination. This study found that two types of scanning range were used, including 140 mm and 160 mm. The results stated that 140 mm of scanning range produces 40% lower effective dose compared to 160 mm. Figure 1 shows the comparison effective dose received between two scanning range. Previous study by Halliburton et al. 2012 [7] mentioned that a scan length of 100 mm may be sufficient enough for evaluation of the coronary arteries in some patients. Moreover, other studies also reported that with an increase in scanning range of 1cm will increase the DLP by 5% which leads to an increase in the effective dose [11]. It is highly recommended that a proper breathing technique should be consulted and practised with the patient prior scanning time to minimize differences in the position of the diaphragm and heart between scans in order to optimize scanning range. Second strategy of dose reduction is using tube current modulation (TCM). TCM technique allows adjustment of the tube current based on patient size, shape and geometry of body in order to obtain lower radiation dose [7]. Previous study reported that effective dose was reduced
around 20-60% when TCM was implemented [11] which was proved by the results in our study. In addition, this study also used the adaptive iterative dose reduction (AIDR) throughout the procedure. As stated in the previous report, AIDR is capable of achieving up to 50% of dose reduction [10].

On the other notes, gender comparisons associated with radiation dose were also investigated in this study. The finding of this study show that male has been higher effective dose compared to female, same in line with previous study by Karim et al. 2019, [5] but comparisons are not possible because these study not specify to CCTA examination. Figure 1 show effective dose between gender. Despite that, effective dose in male and female still lowered than NDRL. The reasons of this results, because of effective dose has no effect among genders but depending on other contributing factors such as patients characteristic and scanning parameter, despite of this statements has not been verified in available studies. However, differences in effective dose between male and female patients in this study were insignificant.

There are several limitations existed in this study. Firstly, this study was limited by the small sample size which is 98 patients in both study groups. This was due to the delayed operation of the CT system which was only begun in January 2018. Secondly, not all patients who came for the coronary CT examination will undergo the coronary CT angiographic examination because sometimes, only calcium score examination was required. Thirdly, lack of patient information such as height, weight, and BMI recorded in the system. This limited data information made the analysis became more difficult. More demographic data such as BMI, heart rate information and manipulation scanning parameter should be obtained in the system in future for the benefit of research output.

**Table 3. Comparison with others generation.**

| Publication          | No of patients | No detector collimation | Effective dose |
|----------------------|----------------|-------------------------|----------------|
| This study           | 98             | 320 x 0.5               | 5.23           |
| Dewey et al. 2009 [2]| 30             | 320 x 0.5               | 8.1            |
| Rybicki et al.2008 [8]| 6              | 320 x 0.5               | 14             |
| Efstathopoulos et al. 2009 [3]| 15 | 128 x 0.625            | 13.4           |
| Hausleiter et al. 2006 [4]| 68          | 64 x 0.6                | 14.8           |
| Earls et al. 2008 [6]| 82             | 64 x 0.625              | 18.4           |
| Hausleiter et al. 2006 [4]| 60          | 16 x 0.75               | 10.6           |
| Coles et al. 2006 [11]| 180           | 16 x 0.75               | 14.7           |

**Figure 1.** Effective dose received between two scanning range and between patients gender.
5. Conclusion
In conclusion, the aim of this study has been successfully achieved which was to evaluate radiation dose associated with prospective ECG-triggering technique and to compare with other established references. Three crucial findings were highlighted from this study such as effective dose received from CCTA examination in UKMMC was significantly lower by 57% difference compared to that national dose reference level (NDRL) due to the use of sequential scanning and data acquisition only in selected cardiac phase. Other than that, this study has proved that 640-slice CT technology can reduce radiation dose by using the technology of wide area detector with 16cm z-axis coverage. This study that further lower radiation dose can be achieved by using proper dose reduction strategy method during CCTA examination such as minimizing scanning range and proper breathing technique. We recommend that, sample size should be increased and demographic data such as BMI, heart rate information and manipulation scanning parameter should be marked in the system for future research.

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