นิพนธ์ต้นฉบับ • Original Article

การเปรียบเทียบปริมาณรังสีที่ผู้ป่วยได้รับจากการตรวจหลอดเลือดหัวใจโดยเครื่องเอกซเรย์คอมพิวเตอร์ชนิด 128 สไลซ์โดยวิธี prospective และ retrospective ECG-triggering

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Comparison of Patient Radiation Dose for 128-Row Multidetector Coronary Computed Tomography Angiography by Prospective Versus Retrospective ECG-Triggering Techniques

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วัตถุประสงค์: เพื่อศึกษาถึงปริมาณรังสีที่ได้รับทั้งหมดในอวัยวะของผู้ป่วยที่ได้รับการตรวจหลอดเลือดหัวใจโดยเครื่องเอกซเรย์คอมพิวเตอร์โดยวิธี prospective และ retrospective ECG-triggering

วิธีการศึกษา: ศึกษาข้อมูลย้อนหลังของผู้ป่วย 233 ราย ที่ได้รับการส่งตรวจหลอดเลือดหัวใจโดยเครื่องเอกซเรย์คอมพิวเตอร์ในด้านปริมาณรังสีที่ได้รับทั้งหมดในอวัยวะของผู้ป่วย โดยผู้ป่วยได้รับการตรวจโดยวิธีที่แตกต่างกันซึ่งขึ้นอยู่กับอัตราการเต้นของหัวใจผู้ป่วย

ผลการศึกษา: ปริมาณรังสีที่ได้รับทั้งหมดในอวัยวะของผู้ป่วยที่ได้รับการตรวจหลอดเลือดหัวใจโดยเครื่องเอกซเรย์คอมพิวเตอร์มีค่าเฉลี่ย 2.8 ถึง 11.5 mSv วิธีการตรวจโดย Prospective ECG-triggering (PT) สามารถทำให้ผู้ป่วยได้รับปริมาณรังสีลดลงถึงร้อยละ 64 เมื่อเทียบกับการตรวจโดย Retrospective ECG-triggering (RT)

สรุป: เนื่องจากปริมาณรังสีที่ได้รับทั้งหมดในอวัยวะของผู้ป่วยที่ได้รับการตรวจหลอดเลือดหัวใจโดยเครื่องเอกซเรย์คอมพิวเตอร์มีค่าแตกต่างกันมาก จากวิธีการตรวจที่ต่างกันดังนั้นรังสีแพทย์และนักรังสีเทคนิคต้องตระหนักถึงความสำคัญและเลือกใช้วิธีการตรวจที่เหมาะสมกับผู้ป่วยแต่ละราย

คำสำคัญ: ปริมาณรังสีที่ผู้ป่วยได้รับการตรวจหลอดเลือดหัวใจโดยเครื่องเอกซเรย์คอมพิวเตอร์ การตรวจหลอดเลือดหัวใจ, เครื่องเอกซเรย์คอมพิวเตอร์

Background and objective: To patient radiation dose in a group of patients who underwent 128-row multidetector coronary computed tomography angiography (CCTA) performed with prospective electrocardiographic (ECG) triggering with radiation dose in a group of patients who underwent CCTA performed with retrospective ECG-triggering.

Method: We performed a retrospective review of 233 consecutive patients referred for CCTA. CCTAs was performed using different scanning protocols depend on patient's heart rate. The effective radiation dose was calculated for each patient.

Results: Depending on different dose saving techniques and heart rate, the effective whole-body dose of a cardiac scan ranged from 2.8 to 11.5 mSv. Prospective ECG-triggering (PT) has the greatest potential to reduce the effective dose to 64 %, compared to a comparable scan protocol with retrospective ECG-triggering (RT).

Conclusion: Due to this broad variability in radiation exposure of coronary CTA, the radiologist and technician should be aware of the different dose reduction strategies.

Keywords: Radiation exposure, Coronary CTA, CT angiography, Computed Tomography

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Introduction

Coronary computed tomography angiography (CCTA) has increasingly gained importance as a noninvasive, fast and accurate study for diagnosing coronary artery disease (CAD).[1-7] The relatively high radiation exposure in CCTA compared with invasive conventional coronary angiography still remains a challenge.[8,9] Hence, not only careful selection of patients suitable for CCTA examination, but reduction of the patient radiation exposure in CCTA without compromising diagnostic accuracy should also be aimed for. CCTA performed with 64-detector CT without the use of ECG pulsing typically result in radiation doses ranging from 15 to 21 mSv [5] and 9 mSv with the use of ECG pulsing.[10,11]

It is well known that the radiation dose in cardiac imaging can substantially be reduced by the use of prospective ECG-triggering data acquisitions.[12] The method of prospective ECG-triggering (PT) has been evaluated for image quality of the coronary arteries and diagnostic accuracy as well as effective radiation dose in several studies.[13-19] Prospective ECG-triggering (PT) is a technique used with CCTA that uses forward-looking prediction of R wave timing, step-and-shoot non spiral acquisition during imaging and unique cone beam reconstruction.[20] By contrast, CCTA with standard retrospective ECG-triggering (RT) uses backward-looking measurement of R wave timing, spiral scanning during table motion and more traditional cone beam reconstruction. In addition, with PT, the x-ray beam is turned on for only a short portion of diastole, and it is turned off during the rest of the R-R cycle, whereas with RT, the x-ray beam is turned on throughout the R-R interval (Fig 1). Initial results showed that PT may be able to provide sufficient image quality with low radiation dose.[13-16] Hence, the purpose of our study was to directly compare a prospective ECG-triggering (PT) technique with retrospectively ECG-triggering (RT) CT techniques in CCTA with respect to effective radiation dose.

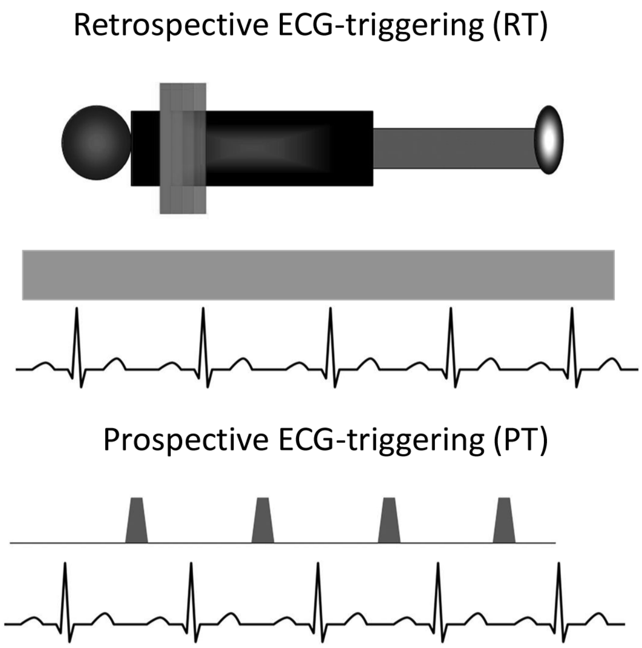

Figure 1 Figure showed retrospective ECG-triggering (RT) and prospective ECG-triggering (PT). With RT technique, the x-ray beam is turned on throughout the R-R cycle. The PT technique is characterised by applying full tube current only at predefined phases of the RR interval and complete pausing of the tube current during the rest of the cardiac cycle, while the table moves to the next imaging position (step-by-step acquisition instead of helical acquisition)

Methods

Patients

This retrospective study included 233 patients (149 males and 84 females) referred for CCTA, between December 2010-December 2011. The indications for CCTA were an abnormal, equivocal or non-diagnostic stress test, chest pain, evaluation of cardiomegaly and congestive heart failure, as well as the evaluation of cardiac etiology of syncope. Patients with an intermediate probability of coronary artery disease (CAD) were also referred for a CCTA as a first test. The above are considered appropriate indications for CCTA, based on the criteria of the American College of Cardiology (ACC)[21] and the recent American Heart Association Scientific Statement on Cardiac CT.[21] Exclusion criteria for CCTA included the presence of multiple ectopic beats, atrial fibrillation, renal failure, pregnancy and a history of allergic reaction to iodine-containing contrast agents. The present study was approved by the Ethics Committee of the Faculty of Medicine, Khon Kaen University, Khon Kaen, Thailand, and informed consent was obtained from all patients.

Cardiac CT Angiography Protocol

CCTA examinations were performed on a 128-slice MDCT (Brilliance 128, Philips Healthcare, Netherland) using prospective (PT) or retrospective (RT) ECG-triggering with the following parameters: 128 × 0.6 collimation, 0.3 sec rotation time, pitch of 0.32, 120 kV tube voltage and 185 reference mAs. Image acquisition was performed during inspiratory breath-hold. To familiarize the patient with the protocol, breath-holding was practiced before the examination. A contrast agent bolus of 80-100 ml was injected with a mean flow rate of 5 mL/s followed by a 50 ml saline flush. For timing purposes, an automated bolus-tracking software was used, starting the scan automatically 6 seconds after contrast agent density in the descending aorta reached a predefined threshold of 130 HU. The entire volume of the heart was covered during one breath-hold in approximately 5 seconds with simultaneous recording of the ECG trace. Patients were scanned in the supine position twice, first without contrast medium to calculate the calcium score and secondly after contrast medium injection. Studies were acquired in the cranio-caudal direction from the level of the carina to just below the diaphragm. For optimal motion-free image quality, data sets were reconstructed in mid diastole (mean interval, 614 ± 175 ms after the R wave). The patients presenting with stable sinus rhythm and a heart rate below 70 beat/min (bpm) we performed CCTA with PT technique and performed CCTA with RT technique for the patients who had minimal cardiac ectopic beats or higher heart rate (more than 70 bpm). Images were first constructed at 75% of the R-R interval; images were then reconstructed at 0%-90% of the R-R interval in 10% increments. Additional reconstruction windows were constructed after examination of initial datasets if motion or noise artifacts were present.

Cardiac CT Angiography Image Reconstruction

All CT datasets were transferred to a dedicated workstation. To evaluate the coronary arteries, the images were reconstructed with a small FOV (120-190 mm), which was restricted to the heart region. The images were reviewed in the axial, coronal, and sagittal planes, using a mediastinal window (width: 450, level: 35), lung window (width: 1,500, level: -700), and bone window (width: 1,500, level: 450) for all examinations.

Measurement of the radiation exposure

The dose-length product (DLP) displayed by the CT unit was recorded for each CCTA. The effective dose of CCTA was estimated by a method proposed by the Fleischner Society.[22] The effective dose is derived from the product of the DLP and a conversion coefficient for the anatomical region examined which is 0.017 mSv mGy^{-1} cm^{-1} for the chest. However, it should be noted that a uniform conversion coefficient for all images is not entirely accurate as it does not account for the different conditions in the examinations.

Statistical analysis

Statistical analyses were performed using SPSS software version 16 (SPSS, Inc., Chicago, IL, USA). Continuous data were expressed as mean±SD and categorical variables were given as percentages. Comparisons of the patient characteristics, the CT parameters and the dose estimates were performed using the t-test for normally distributed data and using the Chi-squared test if not. A significance level of $p < 0.05$ was considered a statistically significant result and all reported *p*-values were two-sided.

Results

Clinical characteristics of the patients are summarized in Table 1. Patients in the prospective ECG-triggering (PT) group and those in the retrospective ECG-triggering (RT) group did not differ significantly in age, sex or mean body mass index. However, there was a significant difference between the groups for mean heart rate (59±9 beats/min for the PT group, 75±11 for the RT group; p<0.03) (Table 1). Depending on different dose saving techniques and heart rate, the effective whole-body dose of a cardiac scan ranged from 2.8 to 11.5 mSv. In PT group, the mean DLP was 184±66 mGy cm, resulting in an effective radiation dose per examination of 3.1±1.1 mSv. In the RG group, mean DLP was 501± 198 mGy cm, resulting in an effective radiation dose per examination of 8.5±3.4 mSv. PT group showed a significantly lower DLP and consequently a significantly lower mean effective radiation dose compared with RG group (p<0.001) (Fig 2). The mean patient radiation dose was 60% lower for prospective gating than for retrospective gating

Table 1 Patient characteristics for the two groups (n=233)

	Prospective gating (n=84)	Retrospective gating (n=149)	p-value
Age (years), mean±SD	59.2±10.5	61.5±9.8	0.85
Male sex$^{\pi}$	50 (60)	99 (66)	0.56
Body mass index(kg/m^2), mean±SD	22.1±6	23.6±5	0.76
Heart rate (beats/min), mean±SD	59±9	75±11	0.03

$^{\pi}$ Data are numbers of patients and data in parentheses are percentages.

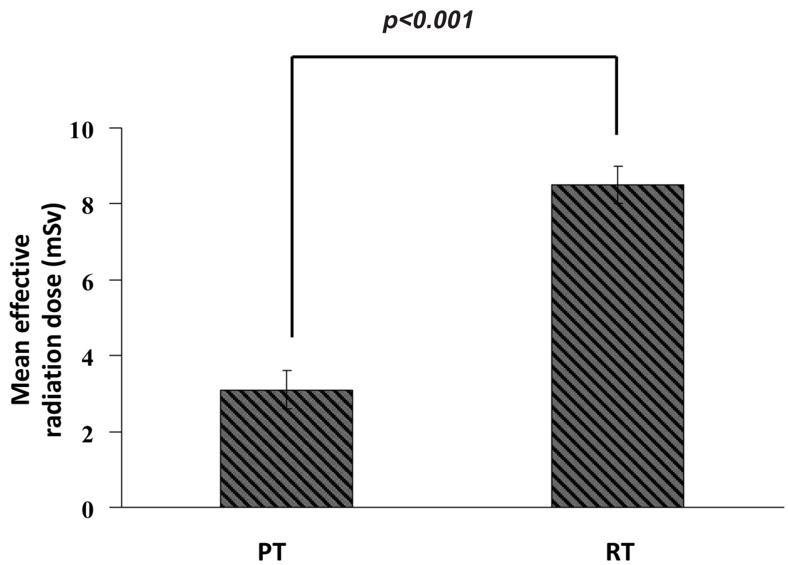

Figure 2 Prospective ECG-triggering (PT) group showed a significantly lower mean effective radiation dose compared with retrospective ECG-triggering (RT) group, p<0.001.

Discussion

The use of CCTA with retrospective gating results in good image quality and few nonevaluable coronary artery segments; however, the radiation dose to patients is relatively high.[23,24] The aim of our study was to directly compare a prospective triggering (PT) CT technique with retrospectively gated (RT) helical CT techniques in CCTA with respect to effective radiation dose. The x-ray beam is turned on throughout the R-R cycle using RT technique. To reduce radiation exposure to the patient we use tube current modulation technique which is uses a stronger tube current during the key imaging portions of diastole and a weaker tube current during the rest of the R-R interval. Still, patients typically receive a radiation dose of 8-19 mSv with intensity-modulated retrospective gating.[24,25]

The technique of prospective triggering itself is characterised by applying full tube current only at predefined phases of the RR interval and complete pausing of the tube current during the rest of the cardiac cycle, while the table moves to the next imaging position (step-by-step acquisition instead of helical acquisition). It has commonly been used for calcium-scoring techniques and has recently been introduced into CCTA protocols: recent studies using single-source 64-slice CT systems have shown that the prospective triggering method offers sufficient image quality of the coronary arteries with substantially reduced effective radiation doses of only 2-4 mSv.[15-20] The major disadvantage of the prospectively ECG-triggered protocol in CCTA lies in the limited predefined interval for data acquisition, which is placed in the mid-diastole phase. As a consequence only images reconstructed from a single phase of the cardiac cycle are available for diagnostic interpretation of the entire coronary artery tree.[26,27]At higher heart rates (>70 bpm) reconstruction of additional data in the systole may be required for diagnostic image quality. Therefore, the prospective triggering mode is typically performed in patients with regular heart beats below 70 bpm. A further drawback to be mentioned when using prospective triggering is that no information on the valvular function[28,29] or global and regional ventricular function[30] can be obtained.

In this study, we compared a group of patients who underwent prospectively gated CCTA with a group of patients who underwent retrospectively gated cardiac CT and who were matched for age, sex, and body mass index. The result of our study showed that mean effective radiation dose in group PT was as low as 3.1±1.1 mSv. In RT group the radiation dose was significantly higher as 7.8±3.4 mSv. We also found that prospective gating resulted in a radiation dose that was 60% lower than that with retrospective gating. Consequently, in patients with a heart rate over 70 bpm the physician has to judge whether retrospectively gated CCTA is an option in the individual patient regarding the relatively high radiation exposure.

Instead, after calculating the risks, administration of beta-blockers before the examination to reduce the heart rate for prospective triggering, or, alternatively, invasive angiography should be considered. Taking into account the advantages and disadvantages of the different techniques, the following guidelines for the selection of different CCTA protocols should be considered. In patients with slow and regular heart rate a protocol with prospective triggering should be chosen, whereas in patients with faster or irregular heart rate retrospective gating should be considered. Tube voltage should be adapted to the patients' body weight.

Conclusion

In the present study, we compared CCTA examinations performed on a 128-slice system using a prospective triggering (PT) technique with retrospective gating (RT) technique, with respect to radiation dose and image quality. The patients presenting with stable sinus rhythm and a heart rate below 70 bpm, CCTA with the PT technique offers a significantly lower effective radiation dose compared with CCTA using RT techniques. However, benefits from prospectively gated cardiac CT must be weighed against two current limitations which are imaging at heart rates higher than 70 beats per minute is not recommended and functional cardiac information is not obtained.

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