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Single- versus multi-phase acquisition protocol for prospective-triggered sequential dual-source CT coronary angiography: comparison of image quality and radiation dose☆

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ABSTRACT

Objective: To investigate image quality and radiation dose of single- versus multi-phase acquisition protocol for prospective-triggered sequential dual-source computed tomography (CT) coronary angiography.
Materials and methods: A total of 140 patients were randomly assigned to single- or multi-phase group. Image quality and radiation dose were compared.
Results: No significant difference was found in image quality between the two groups. Effective dose of single-phase group was 21.6% lower than that of multi-phase group (P<.001).
Conclusions: Prospective-triggered sequential dual-source CT coronary angiography using single-phase protocol can reduce radiation dose without sacrifice of image quality in diastole compared with multi-phase protocol.

1. Introduction

Multi-slice computed tomography coronary angiography (CTCA) is an accurate, rapid, and non-invasive tool for the diagnosis of coronary artery disease [1,2]. Traditionally, CTCA is performed in retrospective electrocardiogram-gated helical acquisition mode with high radiation exposure of 8–18 mSv [3]. Several methods have been introduced to reduce radiation dose in CTCA [4]. Prospective-triggered sequential CTCA, which uses axial or step-and-shoot scan mode, is one of the most promising radiation-saving techniques. Previous studies have demonstrated that significant dose reduction of up to 70% while maintaining similar image quality and diagnostic accuracy can be achieved for prospective-triggered axial acquisition protocol compared with conventional retrospective-gated helical protocol [5–7].

Appropriate patients should be selected strictly when a prospective-triggered acquisition protocol is considered. Typically, a heart rate (HR) of <60–65 bpm was recommended for single-source computed tomography (CT) scanners [4]. Although dual-source CT (DSCT) has a high temporal resolution of 75–83 ms, a low (≤70 bpm) and regular HR was still important for prospective-triggered CTCA using DSCT scanners [4,5,8,9].

Several types of prospective-triggered sequential CTCA technique have been used in DSCT. In the early stage of DSCT, only one set of CTCA data can be obtained at one fixed phase, usually at middle diastole of cardiac cycle [5,9,10]. Its application was limited because no additional data sets of other phases can be used for better selection. Subsequently, the adaptive sequential scan technique allowed multi-phase reconstruction within a narrow window of ±8% cardiac cycle phases [10–12]. A new generation of sequential technique of DSCT extends the scan window to nearly the whole R-R interval. It also allows a flex padding with which the acquisition window can be extended automatically to find the optimum reconstruction phase [13–15]. It gives more flexibility to irregular HRs.

However, widened acquisition window will lead to increased radiation dose. Recent studies using single-source CT scanners showed that prospective-triggered CTCA with narrow acquisition window reduced radiation dose significantly without sacrifice in image quality compared with wide acquisition window [16,17]. For DSCT, little is known about the effect of different padding duration. The purpose of this study was to evaluate image quality and radiation dose of single- versus multi-phase CTCA acquisition protocol with a new adaptive sequential scan technique in diastole using a 64-slice DSCT scanner.

☆ Conflict of interest: None.

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2. Materials and methods

2.1. Patient population

The study was approved by our local review board. Written informed consent was obtained from all patients before the examination. From August 2013 to April 2014, 145 patients with low (HR≤70 bpm) and regular HRs (defined as heart rate variability (HRV)<10 bpm during data acquisition, HRV=maximum HR minus minimum HR) were enrolled in this study. All patients were preferred to CTCA for the evaluation of coronary artery diseases. Exclusion criteria were HR>70 bpm, HRV≥10 bpm, arrhythmia, allergy to iodinated contrast media, impaired renal function, contraindications to beta-blockers and nitroglycerin, patients unable to hold breath, and those with coronary artery stents or bypass grafts. Five patients were excluded because of inability to hold breath. Finally, a total of 140 patients enrolled were randomly assigned to single-phase protocol (group A; $n=70$) or multi-phase protocol (group B; $n=70$). Complete randomization and double blind were used to reduce bias.

2.2. CT protocol and image reconstruction

Patients with HR>65 bpm received oral beta-blockers (50 mg metoprolol tartrate) 1 h before the examination to control HR. All patients without contraindication received nitroglycerin (0.5 mg nitroglycerin tablets) sublingually prior to the scan.

All CT examinations were performed using a 64-slice DSCT scanner (Somatom Definition, Siemens Healthcare, Forchheim, Germany). An adaptive sequential scan technique (Adaptive Cardio Sequence, flex mode) was used to perform the prospective-triggered CTCA. This technique allows automatic extension of the acquisition windows for irregular HRs (Fig. 1). It also employs an arrhythmia rejection algorithm to repeat the scan at the same position in case of ectopic heartbeats. The acquisition window was 70–70% of the R-R interval for group A and 65–75% of the R-R interval for group B. The other scan parameters were same for the two groups: detector collimation, 2×32×0.6 mm; slice acquisition, 2×64×0.6 mm by means of a z flying focal spot; gantry rotation time, 0.33 s; reference tube current-time product, 330 mAs. A low tube voltage of 100 kV was used for patients with a body weight of <90 kg or body weight index of <30 kg/m^2. For those having body weight≥90 kg or body mass index≥30 kg/m^2, the tube voltage was set at 120 kV. The scan length covered the whole heart from the level of pulmonary artery to the diaphragm with 6–8 scan blocks.

The amount of Iohexol injection (Omnipaque 350, 350 mg I/ml; GE Healthcare) was applied according to the body weight (1 ml/kg) of individual patient, followed by 40 ml of 20% blended contrast with saline. The injection rates were range from 4.5 to 5.0 ml/s using a dual-head power injector (Stellant D, Medrad, Indianola, PA, USA). The bolus tracking technique with a threshold of 120 HU in the ascending aorta was selected to trigger data acquisition.

All the CTCA images were reconstructed with a slice thickness of 0.6 mm and an increment of 0.5 mm, using a medium-soft convolution kernel (B26f). One data set was acquired at 70% of the R-R interval in group A. In group B, the best diastolic data set was reconstructed automatically. Multi-phase data sets, including the data set at 70% R-R interval that was used as a virtual single-phase acquisition (group C; $n=70$), were also reconstructed using an interval 2–3% R-R interval for the selection of optimal data set. The optimal data set was selected by an independent senior radiologist in the pre-process stage. In most cases (95.7%, 67/70) of group B, the optimal data sets were the automatically reconstructed best diastolic data sets.

The actual acquisition time of each scan block was recorded. The acquisition time variability (ATV) of scan blocks was defined by the difference between the maximum and minimum block acquisition time for a patient.

2.3. Image evaluation

Preprocessed data sets were sent to a post-processing workstation (MMWP, Siemens Forchheim, Germany). Two skilled radiologists with 6 years of CTCA experience blindly evaluated the image quality independently on per-segment and per-patient bases. A 17-segment model proposed by the American Heart Association was used to assess image quality with a 4-point scale (Fig. 2): 1=excellent, no motion artifacts or noise-related blurring, excellent vessel opacification, and no structural discontinuity; 2=good, minor motion artifacts or noise-related blurring, good vessel opacification, and minimal vessel discontinuity; 3=fair, some motion artifacts or noise-related blurring, fair vessel opacification, or moderate structural discontinuity but sufficient for evaluation; 4=poor, non-diagnostic image quality due to major motion artifacts, severe noise-related blurring, poor vessel opacification, or prominent structural discontinuity [14,18]. Segments with a diameter of less than 1.5 mm were excluded from assessment. Discrepancies were resolved in consultation with a third reviewer with 9 years of CTCA experience. The overall image quality of a patient was defined as the highest score among its segments. A patient was considered undiagnosable if any of the evaluated segments had a quality score of 4.

2.4. Radiation dose estimation

Dose parameters [volume CT dose index and dose length product (DLP)] were recorded. The estimated effective dose was calculated by multiplying the DLP by the conversion coefficient (0.014 mSv·mGy^{-1}·cm^{-1}) for the chest [4]. In order to take into

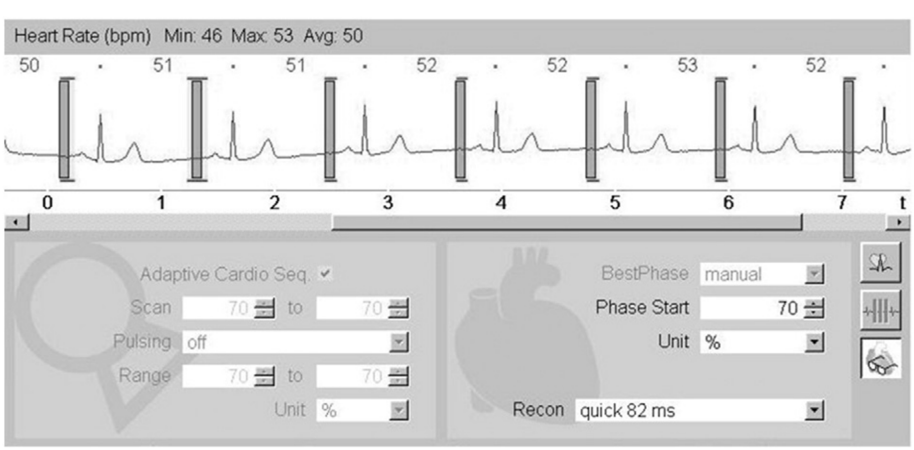

Fig. 1. The acquisition windows were extended automatically in the first two scan blocks for prospective-triggered single-phase acquisition protocol.