Int J Clin Exp Med 2016;9(6):11598-11604
www.ijcem.com /ISSN:1940-5901/IJCEM0023756

Original Article

Value of dual-source CT prospective ECG gate coronary angiography with flex padding technology in patients with sinus tachycardia

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Received January 11, 2016; Accepted May 20, 2016; Epub June 15, 2016; Published June 30, 2016

Abstract: Objective: To investigate the optimal image phase of coronary CT angiography (CTA) imaging analysis for patients with sinus tachycardia. Methods: Fifty-eight patients of sinus tachycardia who were highly suspected to have a potential coronary artery disease (CAD) were scheduled to receive coronary CTA. Flex Pedding technique together with multi-phase imaging reconstruction technology was used in image data collection and analysis. Results: The best construction phase of left anterior descending artery (LAD), left circumflex artery (LCX) and right coronary artery (RCA) from these 58 patients varied. 81.3% of the patients had their best construction phase ranged from 200-250 ms in LAD, with 51.8% of them ranged between 210-240 ms. 65.4% patients had best construction phase of LCX located between 240-260 ms. 70.6% patients had best construction phase of RCA ranged from 280-300 ms. Quality of 40% of the single phase reconstruction images scored at an average of 2.83±0.58, with 58.4% reading the passing rate. After multi-phase reconstruction, this score increased to an average of 3.61±0.64, with a 91.9% passing rate. There was a significant difference between the quality score of single-phase and multi-phase image reconstruction in RCA, LAD and LCS (all $P<0.05$). Conclusion: Combined usage of CT Flex Padding and multi-phase reconstruction was a suitable methodology and key to improve the success rate of coronary CTA in patient with tachycardia.

Keywords: Tomography, x-ray computer, coronary angiography, prospective ECG-gated, sinus tachycardia

Introduction

As we all know, prospective ECG gate coronary angiography can significantly decrease the radiation dosage of patients. However, it has been usually used in patients having stable and low heart rate. Recent studies both from China and abroad have revealed that the application of dual-source CT prospective ECG gate coronary angiography could be expanded to patients with relatively higher heart rate, other kind of arrhythmia or even those with sinus tachycardia due to its greatly improved phase resolution [1, 2]. Due to the obvious difference of coronary artery motions in patients with sinus tachycardia, traditional prospective ECG gate coronary angiography with single source was not able to display branches of coronary arteries clearly. Duel-source CT with Flex Padding technology increased the exposure time from 200 ms to 380 ms such that multisector data could be easily obtained and it has made the multisector reconstruction of prospective ECG gate coronary angiography possible [3, 4]. The overall purpose of this study was to investigate the best image phase of different branches of coronary artery in patients with sinus tachycardia by using Flex Padding and multi-phase reconstruction technologies in prospective ECG gate coronary angiography. We also would like to study whether this combined technology could increase the CT images quality in patients with sinus tachycardia and reduced the radiation dosage for these patients.

Material and method

Clinical data

Fifty-eight subjected that were admitted to our hospital between January 2012 and December

2014 for prospective ECG gate coronary angiography due to a suspected coronary artery disease (CAD) with sinus cardiac rhythm more than 100 beat/minutes (bpm). Among them, 35 cases were male and 23 were female with an average age of 53.3±17.6 years old (ranging from 28 years old to 82 years old). The average heart rate ranged from 101 to 131 bpm with an average of 107.8±14.6 bpm.

Prospective ECG gate coronary angiography

CT scan equipment and patient preparation: The CT scanner used in this study was Siemens duel-source CT (Somatom Definition, Siemens Medical Solutions, Forchheim, Germany). Before the CT scan, patients were fasting for 4-6 hours without using medications to lower heart rate and then patients received sublingual spray twice. CT scanning started from trachea carina to heart diaphragmatic surface. 60-80 ml of nonionic agent Iopamidol was injected through ulnar vein using high pressure syringe at a concentration of 370 mg/ml with injection speed of 5.0 ml/s. After the injection, 40 ml normal saline was injected at the same speed.

CT scan: CT prospective scanning was performed using Flex padding technology with pulse exposure time of 380 ms. CT tube voltage was set up according to the body mass index (BMI) of each patient. Voltage was set at 100 Kv if BMI was ≤25 kg/m^2, while 120 Kv was used if patient's BMI was >25 kg/m^2. Tube current was adjusted using CARE Dose 4D technique with reference current set at 370 ms, collimation of 32×0.6 mm and data collection center phase at 40%. Images were reconstructed using the relative phase of 50% before images were ultimately reconstructed using absolute phase data. The interval of absolute phase reconstruction was 180-320 ms with 10 ms in between two absolute phase. A total of 15 absolute phases were finally reconstruction. Convolution function of the reconstruction was B26f, while B46f was applied as the convolution function of the stents.

Image reconstruction and analysis: The software "Circulation" from Siemens workstation was used to dynamically observe images from different phases. The phase with best image quality for each branches of coronary artery was chosen for the reconstruction, including curved planar reformation (CPR), maximum intensity projection (MIP) and volume rendering (VR). The diseased vessel image was reconstructed at axial view based on MIP.

The severity of the coronary artery narrowing was analyzed according to the guideline of 16-segment method from American Heart Association. For coronary artery segment with diameter ≥1.5 mm, two experience attending physicians in cardiovascular diagnostic imaging evaluated the degree of the narrowing of the vessel independently in a double blind manner. Detailed criteria were as follows: 4 score indicated that coronary artery segment had an intact continuity with equal lumen density and clear margins; 3 score indicated that coronary artery segment had a slight artifact, but with equal lumen density and clear margins so that it did not influence the diagnosis; 2 score indicated that the coronary artery segment had stepped artifacts which influenced the diagnosis although the segment had equal lumen density but blurring margin; score 1 indicated that the coronary artery segment had obvious streak artifacts that final diagnosis was difficult based on the reconstructed image and the segment had unequal lumen density with blurring margin. Images with score ≥3 suggested that the reconstruction was successful and the image met the required quality for diagnosis.

Radiation dose calculation: CT dose index volume (CTDIvol, mGy), dose length product (DLP, mGy*cm) and effective radiation dose (ED, mSv) were recorded and ED was calculated using the formula as follows: ED = DLP×k, where k (k = 0.014) is the dose conversion factor according to the 2008 European quality standard guidelines of CT [5].

Statistics: All statistical analysis was performed using SPSS17.0. Image quality score was presented as mean ± standard deviation (SD) with two-tail independent sample t-test. Measurement of rater's agreement was tested using Kappa test. Kappa <0.4 represented a relatively weak agreement, and Kappa >0.8 represented a strong agreement. Kappa between 0.4 and 0.8 was defined as a moderate agreement between raters. Tests that had P<0.05 was defined as statistically significant.

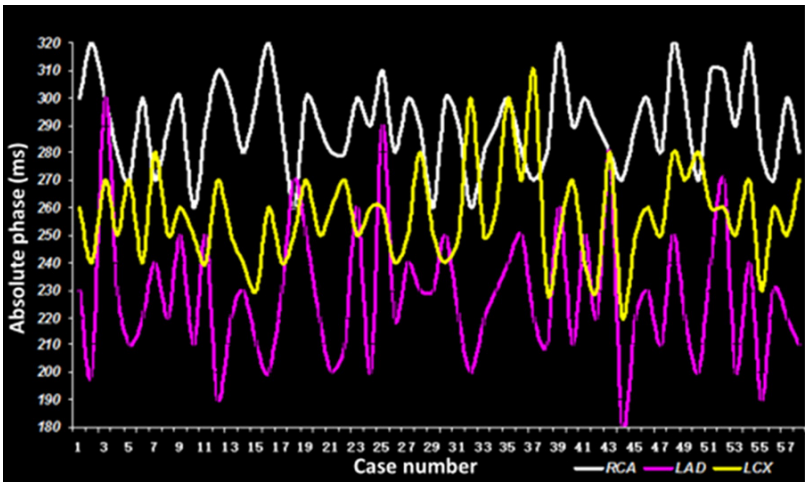

Figure 1. The distribution of best construction phase of LAD, LCX and RCA from 58 patients. Abbreviations: LAD: left anterior descending; LCS: left circumflex coronary artery; bRCA: right coronary artery.

Results

Best construction phase

In all 58 patients, variation existed in the best construction phases of LAD, LCX and RCA from within each individual. However, the best construction phase did have a certain distribution pattern which was shown in **Figure 1**. 65.4% of LCX affected patients had their best construction phase between 240 ms-260 ms, while 70.6% of RCA affected patients had their best construction phase between 280 ms-300 ms. 51.8% of LAD affected patients had their best construction phase between 210 ms-230 ms, and 81.3% of them had their best construction phase between 200 ms-250 ms. Differences of best construction phase for LAD, LCX and RCA also existed in one individual patient as shown in **Figure 1**.

Image quality evaluation

Two individual physicians who were in charge of the image quality evaluation had a good concordance in their scoring (kappa = 0.89). Coronary artery images with high quality were obtained after multi-phase reconstruction and we were still able to get clear images on coronary arteries with relatively lower load of calcified atherosclerotic lesion after lowering the radiation dose of patients (**Figure 2**). In all 58 patients, the average scoring of image quality from single-phase reconstruction (40%) were 2.83±0.58, the pass rate of which was only 58.4%. After multi-phase reconstruction, the average score for images was 3.61±0.64 with 91.9% of them passed the quality control. There were significant differences of the image qualities for RCA, LAD and LCX between single-phase and multi-phase image reconstruction (**Table 1**).

Radiation dosage

The average radiation dose received by these 58 patients were 10.8±0.6 cm. CTDI vol, DLP and ED values were 15.7±5.2 mGy, 169±35 mGy×cm and 2.37±0.49 mSv, respectively.

Discussion

Currently, coronary CT angiography (CTA) has been regarded as the golden standard and primary screening method in the diagnosis of coronary artery disease for general population. However, both patients and physicians have been at higher risk of receiving extra X-ray radiation. Thus, an effective way to reduce the radiation dose is of great urgency. The most effective way to reduce the radiation dose for coronary CTA is to perform a prospective CT scan. Compared with retrospective scan, the former could reduce 80% of the radiation dose for patients without sacrificing the quality of the images and the diagnosis accuracy [5-7]. However, such advantage seemed to only exist in patients with normal heart rate, while images quality from patients with higher heart rate or sinus tachycardia could not be guaranteed. Recently, studies from both China and other countries have revealed that CT prospective ECG gate coronary angiography could also possibly be used in patients with higher heart rate like tachycardia and other arrhythmia [3, 4, 8].

Arrhythmia used to be the “prohibited area” for coronary CTA. However, with the development of technology for CT scanning including the development of EKG editing of low-pitch prospective helical scanning, multiple acquisition technique for wide multi-detector CT and adap-

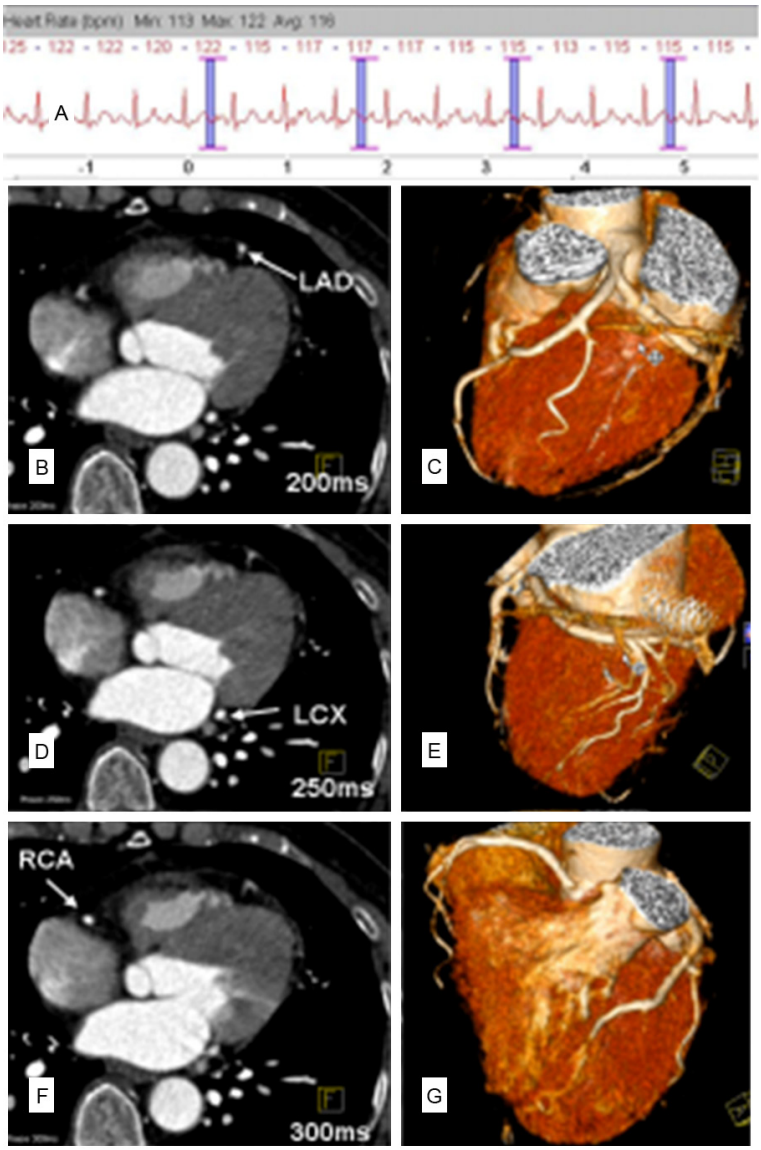

Figure 2. Male, 48 years old with BMI of 25.4 kg/m^2. A. Average heart rate from EKG was 116 bpm. B, C. Reconstruction phase was 200 ms and LAD was shown clearly, while LCX was a little bit blurring. D, E. Reconstruction phase was 250 ms and LCX was clearly shown, while image for RCA was slightly blurring and image for LAD was unclear. F, G. Reconstruction phase was 300 ms. RCA was clearly shown while neither LAD nor LCX was able to be clearly displayed. This indicated that different reconstruction time using single-phase reconstruction method was not able to show clear images of LAD, LCX and RCA at the same time. After multi-phase reconstruction, the score of the image quality was able to read an average of 4.

tive scanning, coronary CTA has no longer been the contraindication for patients with arrhythmia. However, these technologies had their own disadvantages. For example, the radiation dose of patient received low-pitch prospective helical scanning was relatively high, and the EKG editing was time and labor consuming. Wide multi-detector CT had its time limitation for a single acquisition. Patients with higher heart rate needed multiple acquisition with multiple span reconstruction which potentially led to the increased radiation dose for these patients and the risk of image splitting [9, 10]. However, the reality was that about 10% of the patients who planned to receive coronary CTA had arrhythmia, among which sinus tachycardia (sinus rhythm >100 bpm) was the most common form of arrhythmia [11]. The resolution of first generation of dual source CT was 83 ms, which theoretically was suitable for the coronary CTA for patients with any speed of the heart beating. However, there were several issues that had to be solved before coronary CTA could be wildly used without concerns for heart rate issue. There have been relatively small amount of studies investigating the application of coronary CTA in patients with high heart rate. Vembar et al. [12] found that the motion rage of RCA, LAD and LCX differed within the same cardiac cycle from an individual patient. Therefore, to obtain high quality coronary CTA images, a reconstruction phase with relatively lower motion of each coronary artery branches should be chosen carefully. Chai X et al. proved that CT retrospective ECG gate coronary angiography was suitable for patients of sinus tachycardia, although the overall radiation dose for retrospective scan was much higher than prospective scan [13]. Some patients took β blocker to reduce the heart rate, but with less effect and others might have contraindications for β blocker so that medication could not always be used to bring down the heart rate in patients who were going to received coronary

Table 1. Comparison of image quality score of different segments of coronary between single-phase (40%) and multi-phase reconstruction

Segments	Single-phase	Multi-phase	T	P
Major branch of left coronary artery	3.68±0.15	3.91±0.11	0.92	0.175
Proximal segment of LAD	3.43±0.42	3.72±0.27	4.34	0.038
Middle segment of LAD	3.22±0.38	3.58±0.43	8.38	<0.001
Distal segment of LAD	2.78±0.63	3.49±0.36	9.45	<0.001
Proximal segment of LCX	3.25±0.36	3.65±0.53	8.89	<0.001
Distal segment of LCX	2.23±0.71	3.32±0.63	9.34	<0.001
Proximal segment of RCA	2.61±0.66	3.69±0.58	9.67	<0.001
Middle segment of RCA	2.31±0.53	3.53±0.73	9.86	<0.001
Distal segment of RCA	1.92±0.81	3.21±0.77	10.26	<0.001
Average	2.83±0.58	3.61±0.64	8.55	

Abbreviations: LAD: left anterior descending; LCS: left circumflex coronary artery. RCA: right coronary artery.

CTA. If coronary CTA was unavoidable in these patients, prospective CT scan with low radiation dose had to be used under the circumstance of tachycardia according to the principle of as low as reasonably achievable (ALARA).

The application of Flex Padding technique and multi-phage image reconstruction were the key to the prospective CTA for patients with high heart rate. This is due to the theory that Flex Padding technique was able to prolong the pulse exposure time from 200 ms to 380 ms, and expand the scanning window from 220° to 415° so that several single span reconstruction data could be obtained and single-phase reconstruction then became multi-phase reconstruction [3, 4]. By using multi-phase reconstruction, the shadow or constructed defect could be largely avoided so that high quality image could be guaranteed and more accurate diagnosis could be provided to patients. The exposure time used in Flex Padding technique was about 1/3 of the amount needed for retrospective scan. Under the circumstances of same tube voltage and tube current, radiation dose was positively correlated with exposure time, and thus, using Flex Padding to adjust pulse exposure time would be able to reduce the radiation dose significantly. In addition, the radiation dose could be further decrease if iterative reconstruction technique was used.

Matt et al. reported that the best construction phase of patients with tachycardia was between 30-50% of the R-R interval [14]. On the other hand, most of the retrospective CT scanning data was obtained at the systolic phase where the absolute phase should be a fixed time point after R wave on EKG, the method of which had the least impact by heart rate [15]. Image reconstruction should be performed using absolute value at the end of the systolic phase to effectively reduce the artifacts due to the fast heart beat so as to improve the image quality [16]. Out study showed that using 40% of the single phase reconstruction was able to provide an image with an average quality score of 2.83±0.58, while using multi-phase reconstruction based on absolute value could provide images with average quality score of 3.61±0.64. The latter could significantly improve the image quality which suggested that multi-phase image reconstruction was a suitable methodology and key to improve the success rate of coronary CTA in patient with tachycardia.

In this study, the best construction phase for different coronary artery branches ranged between 200 ms and 300 ms. 81.3% of LAD affected patients had their best construction phase between 200 ms-250 ms, while 65.4% of LCX affected patients had their best construction phase between 240 ms-260 ms and 70.6% of RCA affected patients had their best construction phase between 280 ms-300 ms. Compared with the data reported from Philip et al., our best construction phase for RCA, LAD and LCX were 40%, 35% and 40% different, the reason of which might be that they had used retrospective scan and reconstruct images using relative phase while we used prospective scan.

Besides, reducing the tube voltage could significantly decrease the radiation dose received by patients. CARE Dose 4D technique used data from X, Y and Z axis to analyze coronary artery anatomy of each patients and used four-dimensional data obtained from the scanner to adjust the tube voltage accordingly, so that the radiation dose could be reduced without sacri-

ficing the quality of the images [7]. In the current study, we were able to reduce the radiation dose to the lowest level by using both retrospective scanning and personalized tube voltage and tube current for each patient. In our study, the average ED was only 2.37±0.49 mSv, about 1/4 to 1/3 of the dose of retrospective CTA [2, 6].

This study also had some limitations. First of all, we did not have digital subtraction angiography (DSA) data of each patient to be compared with the image quality from CT prospective ECG gate coronary angiography. Therefore, the accuracy of coronary artery lumen narrowing degree based on CT prospective ECG gate coronary angiography could not be fully evaluated. Second, we were not able to analyze the data in subgroups of these 58 patients according to the heart rate, and the upper limit of the heart rate in using CT prospective ECG gate coronary angiography was also not investigated in the current study.

In summary, the combined application of dual source CT Flex Padding technique and multiphase image reconstruction could increase the accuracy of CT prospective ECG gate coronary angiography in the diagnosis of coronary artery disease in patients with sinus tachycardia. At the same time, the radiation dose could be largely reduced, the application of which should be encouraged.

Disclosure of conflict of interest

None.

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