



Automated determination of cardiac rest period on whole-heart coronary magnetic resonance angiography by extracting high-speed motion of coronary arteries

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ABSTRACT

Purpose: The aim of the present study was to develop an automated system for determining the cardiac rest period during whole-heart coronary magnetic resonance angiography (CMRA) examination.

Materials and methods: Ten healthy male volunteers (25–51 years old, 50–77 beats/min heart rate) were enrolled in this prospective study. A motion area map was generated from a cine image set by extracting high-speed component of cardiac motion, and it was used to specify the rest period in the proposed CMRA. In conventional CMRA, the rest period was determined based on the visual inspection of cine images. Agreement of the start time, end time, and trigger time between the two methods was assessed by the Bland-Altman plot analysis. Two observers visually evaluated the quality of the curved planar reformation (CPR) image of the coronary arteries. **Results:** The proposed method significantly prolonged the start time (mean systematic difference 37.7 ms, $P < 0.05$) compared with the conventional method. Good agreement was observed for the end time (mean systematic difference 8.9 ms) and trigger time (mean systematic difference -28.8 ms) between the two methods. A significantly higher image quality ($P < 0.05$) was provided for the left circumflex artery in the proposed CMRA (mean grading score 3.88) than in conventional CMRA (mean grading score 3.68).

Conclusion: Our system enabled detection of the rest period automatically without operator intervention and demonstrated somewhat higher image quality compared with conventional CMRA. Its use may be useful to improve the imaging workflow for CMRA in clinical practice.

1. Introduction

Coronary artery disease (CAD) is one of the most common causes of death [1, 2]. There are several methods to diagnosis CAD such as X-ray coronary angiography [3] and coronary computed tomography (CT) angiography [4]. However, radiation exposure to patients and its risk of carcinogenesis are serious concerns, especially for children [5, 6]. Furthermore, these imaging techniques using contrast materials are inapplicable for patients with severe kidney dysfunction.

Along with advances in magnetic resonance imaging (MRI), whole-heart coronary magnetic resonance angiography (CMRA) enables non-invasive, radiation-free, and contrast material-free examination of CAD [7, 8]. Suppression of motion artifacts is particularly important for CMRA. Data acquisition should be carried out during the mid- to late-

diastolic phase of the heart (cardiac rest period) in combination with the end-expiration phase. Diaphragm navigators and electrocardiogram (ECG)-gate navigators are often used in conventional CMRA. Although the diaphragm navigator automatically detects the end-expiration phase, operators are required to manually specify the cardiac rest period by visual inspection of cardiac motion on cine images. Therefore, image quality is highly dependent on the operator's skill.

Accordingly, the aim of the present study was to develop an automated system to determine the cardiac rest period during CMRA. By analyzing the high-speed motion of the heart in a cine image set, we specified the cardiac phase optimal for data acquisition. The proposed CMRA produced higher quality coronary artery images than conventional CMRA.

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2. Methods

2.1. Subjects

The subjects consisted of ten healthy male volunteers without heart or respiratory diseases. The mean age and mean heart rate were 36.5 years old (range 25–51) and 65.1 beats/min (range 50–77), respectively. Ethical approval for this prospective study was obtained from the Ethical Committee of Tsuchiya General Hospital. Informed consent was obtained from each subject.

2.2. MRI scanner and image sequences

A 1.5-tesla MRI scanner (Intera Achieva, Philips Healthcare, Best, Netherlands) with a 5-channel SENSitivity Encoding (SENSE) cardiac phased array coil was used in all imaging procedures. A weight was placed on the abdomen, and an abdominal compression belt was rolled tightly along the side of the ribs to reduce abdominal movement [9].

Cardiac cine imaging was conducted using ECG-gated two-dimensional (2-D) true fast imaging with steady state precession (true FISP) sequence under breath holding. The imaging parameters were as follows: 3.3 ms repetition time (TR), 1.65 ms echo time (TE), 60 degree flip angle, 400 × 400 mm field of view (FOV), 176 × 133 matrix, and 6 mm slice thickness. Four-chamber long-axis planes (80 frames per heart cycle) were scanned to evaluate myocardial wall motion.

The proposed and conventional CMRA were carried out using a 3-dimensional (3-D) segmented true FISP sequence under free breathing. The imaging parameters were as follows: 4.14 ms TR, 2.07 ms TE, 80 degree flip angle, 300 × 300 mm FOV, 224 × 224 matrix, and 0.85 mm slice thickness. The diaphragm navigator was located on the top of the right diaphragm, and scan data were collected in the end-expiratory phase. For conventional CMRA, operators manually determined the data acquisition timing (cardiac rest period) based on visual inspection of the cine images. Three radiological technologists with > 5 years of experience in CMRA imaging assessed the cardiac phase representing the least motion of the heart, and determined the start time and end time by mutual agreement.

2.3. High-speed cine image

The proposed CMRA was conducted immediately after conventional CMRA. In the proposed CMRA, a cine image set was analyzed to specify cardiac regions representing high-speed motion (Fig. 1). A one-dimensional (1-D) temporal profile of the pixel value was extracted from a cine image set, and cardiac motion $F(k)$ was generated by Fourier transformation of the profile as follows:

$$F(k)_{(x,y)} = \sum_{n=0}^{N-1} f(n)_{(x,y)} e^{-j2\pi kn/N} \quad (1)$$

where k is the frequency (Hz), $f(n)_{(x,y)}$ is the 1-D temporal profile at an arbitrary coordinate on the 2-D cine image, n is the frame number of the cine image, N is the total frame number, and j is the imaginary number. Moreover, the high-speed component of the cardiac motion $X(k)$ was extracted using a high-pass filter, and a preliminary high-speed cine image $F'(n)$ was obtained by inverse Fourier transformation of $X(k)$ as follows:

$$X(k)_{(x,y)} = F(k)_{(x,y)} \times H(k)_{(x,y)} \quad (2)$$

$$F'(n)_{(x,y)} = \frac{1}{N} \sum_{k=0}^{N-1} X(k)_{(x,y)} e^{j2\pi kn/N} \quad (3)$$

where $H(k)$ is a filter coefficient. The filter coefficient was calculated in the preliminary study. When $H(k)$ was set at 83%, the high-speed component was successfully differentiated from the low-speed component.

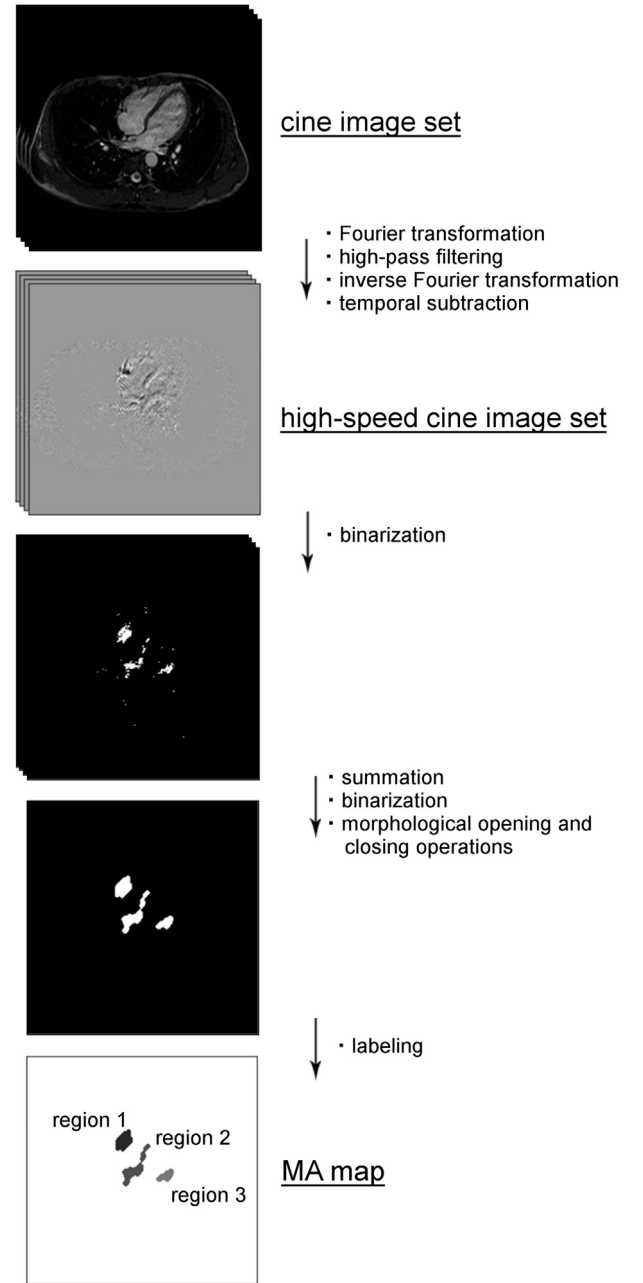


Fig. 1. Image processing during the proposed whole-heart coronary magnetic resonance angiography (CMRA). The high-speed component of cardiac motion was extracted from a cine image set by combination of Fourier transformation, high-pass filtering, inverse Fourier transformation, and temporal subtraction processing, resulting in a high-speed cine image set. A motion area (MA) map was then created by the threshold and binarization processing of the high-speed cine image set. The MA map shows three labeled regions representing high-speed cardiac motion.

After the inverse Fourier transformation, temporal subtraction processing [10] was conducted to emphasize the high-speed cardiac motion as follows:

$$P(i)_{(x,y)} = F'(n+1)_{(x,y)} - F'(n)_{(x,y)} \quad (4)$$

where i is the frame number of the subtraction image set. The subtraction image $P(i)$ was defined as a high-speed cine image and used for creating the motion area (MA) map.

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