Original Investigations

Automatic Determination of Differential Coronary Artery Motion Minima for Cardiac Computed Tomography Optimal Phase Selection

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Rationale and Objectives: Selecting the optimal phase for coronary artery evaluation can be challenging, especially at higher heart rates, given that the optimal phase may differ for each of the coronary arteries. This study aimed to evaluate a novel vessel-specific algorithm which automatically outputs the minimum motion phase per coronary artery.

Materials and Methods: The study included 44 patients who underwent 256-slice cardiac computed tomography for evaluation of chest pain. End-systolic and mid-diastolic minimal motion phases were automatically calculated by a previously validated global motion algorithm and by a new vessel-specific algorithm which calculates the minimum motion for each of the three main coronary arteries, separately. Two readers blindly evaluated all coronary segments for image quality. Median scores per coronary artery were compared by the Wilcoxon signed rank test.

Results: The variation, per patient, between the optimal phases of the three coronary arteries was 5.0 $\pm$ 4.5% (1%–22%) for end systole and 4.8 $\pm$ 4.1% (0%–19%) for mid diastole. The mean image quality scores per coronary artery were 4.0 $\pm$ 0.61 for the vessel-specific approach and 3.80 $\pm$ 0.69 for the global phase selection ($P < .001$). Overall, 46 of 122 arteries had a better score with the vessel-specific approach and five with the standard global approach. Interreader agreement was substantial ($k = 0.72$).

Conclusions: This study has shown that multiple phases are required to ensure optimal image quality for all three coronary arteries and that a vessel-specific phase selection algorithm achieves superior results to the standard global approach.

Key Words: Cardiac computed tomography; coronary artery phase selection; coronary arteries; coronary artery motion; image quality.

Interpretation of computed tomography coronary angiography (CTCA) is usually performed on a single phase of the cardiac cycle. The optimal phase is usually selected empirically or with help of various automatic algorithms. However, it has been shown that the optimal quiet phase often differs for each coronary artery, especially at higher heart rates (1,2).

To avoid motion artifacts, CTCA image analysis is performed on the phase(s) with the least cardiac motion; however, there is currently no consensus concerning the selection of phases with the least cardiac motion. Several studies have attempted to determine the optimal cardiac quiescent phase (3–5), but definition of population-based quiescent phases is challenging because of high interpatient variability and significant heart rate dependency. Furthermore, the electrocardiographic (ECG) waveform by which CTCA acquisition is synchronized does not always adequately represent cardiac motion.

Current phase selection approaches vary from reconstructing 10–20 phases in 5%–10% increments across the cardiac cycle to reconstructing one or two predefined phases empirically or based on automatic global motion minima at end-systolic (ES) and/or mid-diastolic (MD) rest periods (6–9). The former approach is time consuming and confers a high bandwidth and storage burden because it entails reconstructing and reviewing multiple high-resolution data sets, while generating >4000 transaxial images per patient. Although the latter approach of reconstructing one or two predefined phases is more common and reduces some of the data reconstruction, transfer, storage, and image review burdens, it may not provide phases with motion-free images in all patients (7–9).

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Finding the optimal phase or phases can be challenging, particularly in patients with higher heart rates. Furthermore, significant intervessel differences in physiologic rest phase location and duration can exist within left and right coronary artery systems of the same patient (1,2). Yet still, within a vessel, motion patterns can differ between proximal, middle, and distal portions of the same coronary artery (10).

An automated patient-specific phase selection approach for CTCA was introduced in 2004 (6) and has been evaluated in a small cohort using 16-slice MDCT with a good agreement found between automatic and manual phase selection methods (2). Similar results were obtained by Ruzsics et al. (8), Joemai et al. (7), and Seifarth et al. (9) who studied the application of automatic phase selection algorithms on 64-slice MDCT. More recently, an automated vessel-specific phase selection algorithm technology was proposed (11,12), which analyzes the relative motion velocity of each of the three main coronary arteries to extract vessel-specific rest phases; however, this method has not been tested clinically.

Accordingly, the aims of this study were 1) to compare resulting image quality (IQ) per coronary artery, from the new automatic vessel-specific phase selection algorithm, to a previously validated, global rest phase selection algorithm, and 2) to examine the variability in the quiet phase between the coronary arteries.

MATERIALS AND METHODS

This was a single-center prospective study including 44 patients with a low-to-intermediate likelihood of coronary artery disease. All patients were referred for the noninvasive rule-out of suspected coronary artery disease and scanned with a retrospectively gated helical CTCA acquisition protocol. Exclusion criteria were prospective gating, prior coronary artery bypass grafts surgery, valve implants, arrhythmia, renal failure, and pregnancy. Patients with prior coronary bypass surgery were excluded because the algorithm is only useful for native coronary arteries and not for grafts. Valve implants were excluded as metal artifacts may make certain coronary segments noninterpretable for reasons not connected with motion. The study was approved by our institutional review board (IRB). The need for patient consent was waived as no deviation from routine clinical practice CT imaging occurred. The projectional raw data sets were copied to a dedicated research platform for the purpose of this study without any interference with the "standard of care" workflow. Data sets were analyzed on the research platform only after full anonymization.

Data Acquisition

Immediately before the scan, all patients were administered nitroglycerine spray, unless their systolic blood pressure was <100 mm Hg. Beta blockers were not given unless indicated clinically. CTCA was performed on a 256-slice MDCT scanner (Brilliance iCT; Philips Healthcare, Cleveland, OH). The scanner has a 128 × 0.625-mm detector configuration, with a dynamic z-flying focal spot technology which doubles the sampling rate in the z direction, providing simultaneous acquisition of 256 slices per gantry rotation. The gantry rotation time 0.27 seconds resulted in a standard temporal resolution of 135 milliseconds, further optimized for each voxel via adaptive multicycle cardiac reconstructions (13). The acquisitions were performed from the level of carina to the diaphragm at 120 kVp, 800–1000 mAs (effective) and a pitch of 0.16. ECG-triggered tube current modulation (DoseRight Cardiac; Philips Healthcare, Cleveland, OH) was used with maximum tube current between phases 35% and 80%. Because the tube current decays gradually, high-quality images could be obtained at least for phases 30%–85% and sometimes more. A standard amount of 80 mL of contrast media (Imeron 400; Bracco, Milano, Italy), not corrected for BMI, was injected at 6 cc/s followed by 50 mL of saline injected at the same rate. Using bolus tracking, scans were initiated when contrast enhancement in a region of interest in descending aorta reached a preset threshold of 100 Hounsfield units. With an average scan length of 13 cm, the scans were completed in 6 seconds.

Automated Global Phase Selection

First introduced in 2004 (7,8), this approach consists of generating low-resolution gated images at high temporal sampling across the cardiac cycle. On the basis of the object similarity between adjacent phases of the cardiac cycle, motion is determined and resolved spatially to generate optimized cardiac reconstructions. This was evaluated in a small cohort using 16-slice MDCT with a good agreement found between automatic and manual phase selection methods (2).

Automated Vessel-Specific *Phase selection*

This technique (11,12) uses projection data as input, first generating low-resolution images with high temporal sampling. These reduced-matrix high temporal-sampled image volumes are automatically segmented making use of fully automatic model-based cardiac segmentation algorithms (14,15) to obtain the surface mesh of each of the cardiac chambers, encoded with a priori information about the expected location and course of the coronary arteries (Fig 1). This operation is performed in a progressive manner, with results from one phase subsequently propagated to adjacent phases, to optimize computational efficiency. The individual coronary artery encoded regions are subsequently analyzed according to their relative motion velocity and used to extract vessel-specific rest phases (Fig 2). The entire operation is fully automatic, the final output being the production of an ES and an MD rest phase for each coronary artery.