Original Investigation

Reconstructions Using RIF in Motion Mapping Technique Have Substantially Less Arrhythmogenic Artifacts in Dual-source Coronary CTA

Sebastian Daniel Reinartz, MD, Markus Winkler, Sascha B. Diefenbach, Thomas Allmendinger, PhD, Tobias Penzkofer, MD, Christiane K. Kuhl, Prof., MD, Andreas H. Mahnken, Prof., MD

Rationale and Objectives: Particularly for patients with heart arrhythmias, conventional BestSystole (BS) and BestDiastole (BD) reconstruction techniques in computed tomography (CT) frequently show artifacts that hinder the readability of the coronary tree. To address this problem, this paper presents an alternative reconstruction method that combines the technique "reconstructions with identical filling" (RIF) with motion mapping: This new technique is called "RIF in motion mapping" (RIMM). This study compares the diagnostic quality of images generated with RIMM to that of the other reconstruction techniques.

Materials and Methods: Having shown major artifacts in standard reconstructions, the CT datasets of 23 patients with suspected coronary artery disease or prior to transcatheter aortic valve replacement were selected manually. Each dataset was evaluated with four reconstruction techniques: BS, BD, RIF, and RIMM. Two radiologists, blinded to the applied reconstruction type, then evaluated the entire coronary tree of each sample using the 15-segment American Heart Association model and the six-grade Likert scale.

Results: Of the 345 analyzed coronary segments, the RIMM technique showed a significant number of images with reliable diagnostic quality ($n = 228$, 66%) as compared to RIF ($P = 0.002$) and BS/BD reconstructions ($P < 0.001$). Per coronary segment, vessel, and patient, the RIMM technique scored significantly better than the conventional BS/BD reconstructions ($P = 0.003$) and better than the RIF reconstructions with regard to the right coronary artery ($P = 0.041$).

Conclusions: This new technique works: Using RIMM on the worst CT images substantially erased many of these artifacts, thereby enabling the radiologists to clearly visualize these segments. As RIMM considerably eliminates artifacts, this new CT reconstruction technique can help make a fast reliable evaluation of a patient's coronary tree. Thus, this enhanced visualization of cardiac images by RIMM avoids the need for further invasive diagnostic procedures.

Key Words: Reconstruction technique; cardiac computed tomography; image quality; arrhythmia; radiological technology.

INTRODUCTION

Dual-source coronary computed tomography angiography (cCTA) has become a routine method to noninvasively assess the coronary arteries of patients with low or intermediate probability for having coronary artery disease, or to evaluate the patency of coronary artery bypass grafts (1,2). This technique has also become a prerequisite to planning transcatheter aortic valve replacement (TAVR). Because atrial fibrillation is a common problem particularly in older patients (an incidence of approximately 4% in patients older than 60 years and 9% in octogenarians), this cohort typical characterizes TAVR recruits in the United States (3) and in Europe (4,5).

In general, manufacturers' standard reconstructions, which yield systolic and diastolic reconstructions, are applied. In 2009, BestPhase was introduced (6) to calculate reconstruction points based on motion maps. This works by generating a three-dimensional density matrix of the heart for every time point after the R-wave. Then, changes in voxel values are

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From the Department of Diagnostic and Interventional Radiology, University hospital RWTH Aachen, Pauwelsstrasse 30, Aachen 52074, Germany (S.D.R., M.W., S.B.D., C.K.K.); Computed Tomography, Siemens Medical Healthcare, Forchheim (T.A.); Department of Diagnostic and Interventional Radiology, Charite University Hospital, Berlin University, Berlin (T.P.); Department of Diagnostic and Interventional Radiology, University Hospital, Philipps University Marburg, Marburg, Germany (A.H.M.). Received February 15, 2016; revised August 23, 2016; accepted September 23, 2016. **Address correspondence to:** S.D.R. e-mail: Sebastian.D.Reinartz@rwth-aachen.de

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compared over time to calculate a so-called "motion map." The minimal changes in systole and diastole are identified and used as starting points for reconstructions.

However, unpredictable arrhythmias and premature beats, characteristically seen especially in TAVR patients or in patients with atrial fibrillation, often result in CT image artifacts, which hinder a precise evaluation of coronary arteries.

Manual Electrocardiogram editing (ECG) (7) is a widely used technique to compensate for artifacts after completion of data acquisition. Even so, reproducing diagnostic image quality greatly depends on the individual observer's experience in choosing the right reconstruction points. Furthermore, artifacts due to arrhythmias, pacemaker stimulation, or premature beats have to be processed specifically (8). Moreover, the width of the ECG gating or triggering interval during the CT scan restricts the number of additional reconstructions. This means that the wider the acquisition interval, the greater the possibility of reconstructions in different time phases during the cardiac cycle. Vice versa, in a narrow interval, eg, 100 ms, only few reconstructions covering only a specific part of the cardiac cycle are technically available.

Another method based on the cardiac pressure-volume relationship generates the so-called "reconstructions with identical filling" of the heart, or RIF in short (9). The RIF technique identifies the time points of the cardiac cycle with physiologically minimal coronary motion based on single and multiple heartbeat isovolumetry. Due to Frank-Starling mechanism, these cardiac phases are harbored in the early diastole, which is commonly not covered by the full-dose ECG gating or triggering interval, and in the slow diastolic filling phase prior to the atrial systole. Because cardiac output is stable over time, independent of the cardiac rhythm, identical passive filling of the left ventricular (LV) is guaranteed. This explains isovolumetry in multiple heartbeats at constant time points after the R-wave.

In the earlier retrospective study (9), in particular for arrhythmic patients, a significant greater number of diagnosable datasets were produces by applying RIF than with standard reconstructions.

Nonetheless, the RIF technique is limited by working with assumptions such as average heart rate or average ECG times. Therefore, to better account for actual conditions in a particular dataset being investigated via CT, the present authors advance the idea of combining the RIF concept with the motion maps concept of CT reconstruction as a symbiosis to overcome the disadvantages of each particular reconstruction technique (RIF, BestSystole [BS], and BestDiastole [BD]). We called the new proposed technique "RIF in motion mapping" (RIMM).

Thus, this paper presents the new RIMM technique to address the problem of poor readability of coronary trees, in particular of patients with heart arrhythmias. This retrospective study, which used poorly readable, artifact-laden, CT image datasets, aims to evaluate the image quality of RIMM reconstructions compared to those generated with RIF and those produced by standard reconstructions based on motion maps.

MATERIALS AND METHODS

RIMM Concept

The RIMM concept combines the RIF and BestPhase concepts. It exploits both the ability of RIF to identify a time point with little coronary movement during multiple heartbeats, as well as the systematic search for minimal movement provided by motion maps. Thus, this new technique is called the "RIF in Motion Mapping (RIMM)." In contrast to standard BestPhase reconstructions, the RIMM leads to diastolic reconstruction points with positive time intervals after the R-wave. The RIMM datasets were experimentally calculated by Recon-CT software ver. 8.0.0.0 (Siemens Healthcare Sector, Forchheim, Germany).

Patients

Twenty-three patients who had shown contraindications to medicinal preparations or an insufficient response to applied beta-blockers (10 men, 13 women; mean age: 71.0 ± 12 years) were retrospectively enrolled in this study. All patients underwent retrospectively ECG-gated cardiac dual-source CT between January 2010 and July 2010 for evaluation of the coronary arteries ($n = 12$, 52%) or in preparation of the TAVR procedure ($n = 11$, 48%). Metoprolol succinate (Beloc-Zok, AstraZeneca, London, UK) at a dose of 47.5 mg p.o. or metoprolol tartrate i.v. (Beloc i.v., AstraZeneca) at a dose of up to 10 mg was administered short time before the examination. One patient received digoxin (Digimerck, Merck KGaA, Darmstadt, Germany).

This study was approved by the local ethics committee, and written informed consent was obtained routinely from all patients prior to this study.

Imaging Protocol

A first-generation dual-source CT scanner (SOMATOM Definition, Siemens Healthcare Sector, Forchheim, Germany) was used in the examination of all patients. The ECG pulsing was applied during these retrospectively ECG-gated examinations, performing a regression to 4% of its nominal value outside the full-dose interval. This interval has been individually adapted, with regard to examiner's experience and the severity of arrhythmia; in some cases, it is turned off. All scans were performed with a 2 × 32 × 0.6 mm collimation, tube voltage of 120 kV, and a gantry rotation time of 330 ms, leading to a temporal resolution of 83 ms. The mean dose was calculated using the conversion coefficient of 0.014 $mSv{\cdot}mGy^{-1}{\cdot}cm^{-1}$.

The department's standard contrast media protocol for cCTA was performed using 30 mL iopromide (Ultravist 370 mg, Bayer, Berlin, Germany) with a flow rate of 6.0 mL/s, followed by 70 mL contrast media at 5.0 mL/s. A saline chaser of 40 mL completed this biphasic protocol. The bolus tracking technique was used, positioning the region of interest in