Original Investigation

Improved Estimation of Coronary Plaque and Luminal Attenuation Using a Vendor-specific Model-based Iterative Reconstruction Algorithm in Contrast-enhanced CT Coronary Angiography

Yoshinori Funama, PhD, Daisuke Utsunomiya, MD, Kenichiro Hirata, MD, Katsuyuki Taguchi, PhD, Takeshi Nakaura, MD, Seitaro Oda, MD, Masafumi Kidoh, MD, Hideaki Yuki, MD, Yasuyuki Yamashita, MD

Rationale and Objectives: To investigate the stabilities of plaque attenuation and coronary lumen for different plaque types, stenotic degrees, lumen densities, and reconstruction methods using coronary vessel phantoms and the visualization of coronary plaques in clinical patients through coronary computed tomography (CT) angiography.

Materials and Methods: We performed 320-detector volume scanning of vessel tubes with stenosis and a tube without stenosis using three types of plaque CT numbers. The stenotic degrees were 50% and 75%. Images were reconstructed with filtered back projection (FBP) and two types of iterative reconstructions (AIDR3D and FIRST [forward-projected model-based iterative reconstruction solution]), with stenotic CT number of approximately 40, 80, and 150 HU (Hounsfield unit), respectively. In each case, the tubing of the coronary vessel was filled with diluted contrast material and distilled water to reach the target lumen CT numbers of approximately 350 HU and 450 HU, and 0 HU, respectively. Peak lumen and plaque CT numbers were measured to calculate the lumen–plaque contrast. In addition, we retrospectively evaluated the image quality with regard to coronary arterial lumen and the plaque in 10 clinical patients on a 4-point scale.

Results: At 50% stenosis, the plaque CT number with contrast enhancement increased for FBP and AIDR3D, and the difference in the plaque CT number with and without contrast enhancement was 15–44 HU for FBP and 10–31 HU for AIDR3D. However, the plaque CT number for FIRST had a smaller variation and the difference with and without contrast enhancement was −12 to 8 HU. The visual evaluation score for the vessel lumen was 2.8 ± 0.6, 3.5 ± 0.5, and 3.7 ± 0.5 for FBP, AIDR3D, and FIRST, respectively.

Conclusions: The FIRST method controls the increase in plaque density and the lumen–plaque contrast. Consequently, it improves the visualization of coronary plaques in coronary CT angiography.

Key Words: Coronary plaque attenuation; lumen–plaque contrast; full statistical iterative reconstruction algorithm; coronary CT angiography.

Acad Radiol 2017; ■:■■–■■

From the Department of Medical Physics, Faculty of Life Sciences, Kumamoto University, 4-24-1 Kuhonji, Kumamoto 862-0976 (Y.F.); Department of Diagnostic Radiology, Faculty of Life Sciences, Kumamoto University, Kumamoto, Japan (D.U., K.H., T.N., S.O., M.K., H.Y., Y.Y.); The Russell H. Morgan Department of Radiology and Radiological Science, The Johns Hopkins University School of Medicine, Baltimore, Maryland (K.T.). Received November 2, 2016; revised February 25, 2017; accepted February 28, 2017. **Address correspondence to:** Y.F. e-mail: funama@kumamoto-u.ac.jp

http://dx.doi.org/10.1016/j.acra.2017.02.006

INTRODUCTION

Coronary computed tomography angiography (CTA) with electrocardiogram (ECG) gating is an accurate noninvasive method to evaluate coronary artery disease (1–4). Potential applications of coronary CTA require high visualization of coronary arteries while maintaining radiation dose (5). In addition, coronary CTA raises concerns regarding evaluations of coronary stenosis and coronary plaque. Previous studies have associated high-risk plaque characteristics (e.g., positive remodeling, low CT number plaque, napkin ring, sign, and spotty calcium), as characterized by coronary CTA, with culprit lesions of the acute coronary syndrome (6–12). Therefore, diagnostic accuracy relies on knowledge of the plaque burden and high-risk plaque features. Regarding coronary plaque, CT number of coronary plaque varies with the increasing contrast enhancement of coronary lumen owing to partial volume effects, beam hardening, and plaque vascularity (13). Noncontrast CTA and dual-phase coronary CTA from noncontrast (first phase) and contrast enhancement (second phase) were previously applied to achieve accurate CT number of the coronary plaque (14–16).

Recently, an algorithm called "forward-projected model-based iterative reconstruction solution" (FIRST) was developed as an iterative method for image reconstructions (17,18). Unlike AIDR3D (19,20), FIRST is an iterative reconstruction algorithm that models system optics, such as the detector element aperture, and improves image quality by iteratively minimizing a penalty-based cost function. FIRST can potentially improve the spatial resolution and CT number because it employs a more accurate model of X-ray physics (considering partial volume effects, beam hardening, etc.) than the former iterative method does, as well as an improved filtered back projection (FBP) method.

Our study aims to investigate the stabilities of plaque attenuation and coronary lumen using coronary vessel phantoms and the visualization of coronary plaques in clinical patients through coronary CTA. Our phantom study involves different plaque combinations (soft, intermediate, and calcified), different stenosis (50% and 75%), different lumen densities (low and high lumen), and different reconstruction methods (FBP, AIDR3D, and FIRST).

MATERIALS AND METHODS

Our retrospective studies were approved by our institutional review board; informed patient consent for the analyses was waived.

Phantom Study

Phantom

For the coronary vessel models, we used three types of vessel tubes with stenosis and an acrylic tube without stenosis (Fuyo, Japan). The length and the inner lumen diameter of the coronary vessel models were 50.0 mm and 3.0 mm, respectively. To investigate cases with different stenotic CT numbers, we used stenotic degrees of 50% and 75% and the stenoses were composed of polystyrene, mono cast nylon, and acrylonitrile butadiene styrene copolymer. In our study, the 50% and 75% stenosis portions were used to mimic moderate and severe stenoses, respectively. We examined three types of plaque, namely, soft, intermediate, and calcified plaques; the stenotic CT number was approximately 40, 80, and 150 HU, respectively. In the case without stenosis, the tubing of the coronary vessel was controlled with diluted contrast material (iopamidol, Isovue 370; Bracco Diagnostics, Princeton, NJ) to reach the target lumen CT numbers of approximately 350 HU (low lumen diameter) and 450 HU (high lumen diameter). Then, we filled the same iodine density in each 50% or 75% stenotic lumen. In the case of simulated non–contrast-enhanced CT, the tubing of the coronary vessel was filled with distilled water. The coronary vessel model was fixed at the center of a water-filled polypropylene square container (26.7 cm wide, 36.3 cm long, and 17.8 cm high).

ECG-gated Single-heartbeat CTA

We performed ECG-gated single-heartbeat coronary CTA prospectively on a third-generation 320-row multidetector CT (MDCT) (Aquilion ONE Genesis; Toshiba Medical Systems, Otawara, Japan) (21–23). The scanner parameters were detector configuration, 320 × 0.5 mm; slice thickness, 0.5 mm; gantry rotation time, 0.275 second; display field of view (FOV), 80 × 80 mm; and matrix, 512 × 512. An ECG was acquired during volume scanning at a simulated 60 bpm heart rate signal using the demo mode for cardiac CT. The tube voltage and the current were 120 kVp and 360 mA, respectively. We set the exposure phase window (padding window) to 75% with the half-scan algorithm for 60 bpm. CT scanning was performed three times for each contrast enhancement scenario and each stenosis. Images were synchronously reconstructed from the ECG data using FBP and two types of iterative reconstruction algorithms (IR: AIDR3D, FIRST; Toshiba Medical Systems) as well as a coronary standard kernel/filter (FC03) for FBP (24), the AIDR3D standard. Unlike FBP and AIDR3D, the FIRST method does not include kernels; rather, different parameters were set depending on the clinical application, e.g., body, bone, and lung. In our study, we used a clinically optimized cardiac parameter, "cardiac sharp," for FIRST. FIRST is expected to provide accurate CT images because additional information concerning the focal spot size (optics model), photoelectric noise (statistical model), cone beam trajectory (cone beam model), and exact scan parameters (system model) is utilized in the iterative process. FIRST includes the forward imaging process that communicates the projection-data domain and the image data domain. The agreement between the measured projection data and the calculated (forward) projection data is maximized while the image-domain regularization controls the image noise and the spatial resolution. The FIRST "cardiac sharp" employs the regularization model focusing on the maximization of high-contrast spatial resolution rather than minimization of image noise. In contrast, the FIRST "body" emphasizes minimization of noise over maximization of spatial resolution. In order to accurately image small structures such as coronary vessels, the FIRST "cardiac sharp" is considered to be appropriate.

Peak CT Number and Plaque CT Number

To analyze the longitudinal lumen planes 0.5 mm multiplanar reformations (MPRs) were conducted (Fig 1). The lumen CT number of pixels along the lumen diameter was measured, and a profile plot was obtained. To measure the profile curve, the rectangular region of interest (ROI) was set at 3.0 × 9.0 mm