Original Investigation

In Vitro Comparison of Second- and Third-generation Dual-source CT for Coronary Stent Visualization at Different Tube Potentials

Tobias Gassenmaier, MD, Nils Petri, MD, Thomas Allmendinger, PhD, Thomas Flohr, PhD, Andreas M. Weng, PhD, Andreas S. Kunz, MD, Bernhard Petritsch, MD, Wolfram Voelker, MD, Thorsten A. Bley, MD

Rationale and Objectives: The study aimed to evaluate in vitro stent lumen visibility of coronary stents in a second- and third-generation dual-source computed tomography (CT) system at 100 and 120 kVp tube potential.

Materials and Methods: Twenty-six coronary stents ranging from 2.25 to 4.0 mm in diameter were implanted in a coronary vessel phantom. Scans were performed at 100 and 120 kVp tube potential. Evaluation was performed using a medium-sharp kernel in both systems (B46f in the second-generation and Bv49 in the third-generation model) and a sharp (Bv59) convolution kernel optimized for vascular imaging in the third-generation CT.

Results: The median visible stent lumen diameter in the second-generation system was higher at 120 kVp with a median of 62.0% compared to 56.3% at 100 kVp ($P < 0.001$). The median visible diameter in the third-generation system was significantly higher applying the Bv49 kernel with 66.7% at 120 kVp and 61.1% at 100 kVp (both $P < 0.001$). When applying the Bv59 kernel, visible stent lumen further increased to 69.3% at 120 kVp and 66.7% at 100 kVp. Additionally, stent lumen was assessed using full width at half maximum, resulting in a comparable increase in luminal diameter at corresponding tube potential.

Conclusions: Third-generation dual-source CT provides superior stent lumen visibility at equivalent tube potential and at reduced tube potential of 100 kVp when compared to 120 kVp in a second-generation system, at least when manually assessed.

Key Words: Multislice computed tomography; coronary angiography; CT angiography; stents; artifacts.

INTRODUCTION

An estimated 492,000 patients underwent percutaneous coronary intervention in the United States in 2010 (1). In-stent restenosis is a major limitation of percutaneous coronary intervention, and although its incidence decreased with the advent of drug-eluting stents it remains in the range of 3%–20% (2). Several thousand coronary angiographies are performed each year to exclude in-stent restenosis, exposing the patient to the minor but definite risks of an invasive procedure. Thus, a noninvasive method for diagnosis or exclusion of in-stent restenosis is desirable.

Yet various stent materials cause different magnitudes of x-ray attenuation, leading to beam hardening and blooming artifacts, and eventually hindering stent lumen assessment. Previous studies have shown that computed tomographic angiography (CTA) might be an appropriate tool for visualization of coronary stents. However, image quality is strongly dependent on the material and architecture of the stents reviewed, as well as the technical capabilities of the computed tomography (CT) system used for evaluation (3,4).

With the introduction of 64-slice CT, the noninvasive detection or exclusion of in-stent restenosis seemed feasible. However, precise quantification was found to be inaccurate, and overall sensitivities and specificities decreased significantly when nonassessable stent segments were included (5,6). In particular, stent diameter proved to play a significant role with respect to coronary stent lumen assessment. Accordingly, diagnostic performance of 64-slice CT for evaluation of in-stent restenosis was limited to larger stents with a diameter of 3 mm or above (5,7).

With the increasing technical capabilities of new CT scanner generations, including the introduction of dual-source CT and

Acad Radiol 2016; ■:■■–■■

From the Department of Diagnostic and Interventional Radiology, University Hospital of Würzburg, Oberdürrbacher Str. 6, 97080 (T.G., A.M.W., A.S.K., B.P., T.A.B.); Department of Internal Medicine I, University Hospital of Würzburg, Würzburg, Germany (N.P., W.V.); Siemens Healthcare, Forchheim, Germany (T.A., T.F.). Received July 11, 2015; revised November 14, 2015; accepted March 14, 2016. **Address correspondence to:** T.G. e-mail: gassenmaie_t@ukw.de

http://dx.doi.org/10.1016/j.acra.2016.03.011

new reconstruction algorithms, various studies have shown a marked improvement in coronary stent visualization by CTA over the last years (8–12). These advances were accompanied by reduced radiation exposure, eventually leading to low-dose coronary CTA with still acceptable image quality and sufficient predictive values even for the detection of in-stent stenosis (13).

It has been demonstrated that third-generation dual-source CT permits coronary stent lumen visibility of up to 80% in metal stents (14). Yet, because of the novelty of both the hardware, as well as the reconstruction algorithms used, the exact dimensions of improvement compared to second-generation CT systems remained unclear. We therefore sought to investigate in vitro stent lumen visibility of 26 commonly used coronary stents in both a second- and third-generation dual-source CT system. Furthermore, we evaluated the effects of reduced tube potential of 100 kVp for coronary stent assessment.

MATERIALS AND METHODS

Experimental Setup

Based on 15 established stent models, 26 balloon-expandable coronary stents differing in size and architecture were reviewed. Utilized stent diameters ranged from 2.25 mm to 4.0 mm. Full details on stent characteristics are provided in Table 1.

For CT evaluation, the stents were each implanted into a heat-shrinkable phantom tube made of polyolefin to simulate a coronary artery. Lumen-dependent wall thickness ranged from 0.1 to 0.5 mm and tube selection was based on intended diameter of the expanded stents.

Stent expansion was performed following the manufacturer's in vitro stent compliance table for intended inner diameter. In the vast majority of stents utilized, intended inner diameter corresponded with nominal diameter as defined by the manufacturer, whereas the TAXUS Liberté, the Cypher, and one of the Orsiro stents were expanded to an inner diameter of 3.0 mm each instead of a nominal diameter of 2.75 mm. Discordant tubes not exactly matching the stent were cautiously heated to shrink and harmonize the tube with the stent's outer diameter, whereas the catheter balloon remained inflated. Subsequently, the tubes were flooded with diluted contrast (Imeron 300, Bracco Imaging, Konstanz, Germany) standardized to 350 HU at 120 kVp. Prior to scanning, the tube was placed in a plastic receptacle containing an emulsion of sunflower oil and Lipiodol Ultra-Fluid (Guerbet, Roissy CdG Cedex, France) standardized to a density of −70 HU, comparable to the attenuation observed in epicardial fat. An institutional review board (IRB) approval was unnecessary for this phantom study.

CT Scan Protocol

Studies were performed in both a second- and a third-generation dual-source CT system (SOMATOM Definition Flash and SOMATOM Force, Siemens Healthcare, Forchheim, Germany). The SOMATOM Definition Flash is equipped with two conventional detectors, one providing 736 detector channels covering a 50-cm scan field of view (SFOV) and the other providing 480 detector channels covering 33 SFOV. In comparison, the SOMATOM Force is equipped with two integrated circuit detectors (Stellar Infinity, Siemens), one providing 920 detector channels to cover a 50-cm SFOV and the other providing 620 detector channels to cover a 35.4-cm SFOV.

All scans were acquired in a retrospectively electrocardiography(ECG)-gated cardiac spiral dual-source mode with simulated ECG signal and a collimation of 64×0.6 mm (second-generation system) and 96×0.6 mm (third-generation system). By means of a z-direction flying focal spot, the number of acquired slices is virtually doubled during data acquisition at a gantry rotation time of 285 ms (128×0.6 mm slice acquisition) with the second-generation system and 250 ms (192×0.6 mm slice acquisition) with the third-generation system.

Scans were performed in an orientation parallel to the scanner's z-axis (ie, 0°) with a tube potential of 100 kVp and 120 kVp, 340 mAs/rot quality reference tube current, and default ECG-based current modulation at 70% RR-interval. Automatic exposure control was active during the acquisitions. Thus, adjustment of the tube current to the size of the phantom based on the topogram information provided a more realistic degree of noise amplitude of the scans.

Data Reconstruction

Acquired CT images were reconstructed to an image slice thickness of 0.6 mm, an increment of 0.3 mm, and a field of view of 170 mm, with an image matrix of 512×512 pixels. Notably, data sets were reconstructed with corresponding medium-sharp convolution kernels in both systems (B46f in the SOMATOM Definition Flash and Bv49 in the SOMATOM Force), and additionally a new sharper convolution kernel (Bv59) in the third-generation system.

In contrast to the previously applied iterative Bv49 kernel, the Bv49 kernel in the current study was based on a weighted filtered back projection algorithm with no additional noise reduction. The modulation transfer function parameters of the B46f are $rho_{50} = 4.83$ lp/cm, $rho_{10} = 7.79$ lp/cm, and $rho_{2} = 9.37$ lp/cm, and of the Bv49 $rho_{50} = 5.62$ lp/cm, $rho_{10} = 8.59$ lp/cm, and $rho_{2} = 9.91$ lp/cm. The very sharp Bv59 kernel remains without equivalent in the former systems and reflects the increased clinical capabilities, in combination with iterative reconstruction, of the new detector system, with modulation transfer function parameters $rho_{50} = 8.32$ lp/cm, $rho_{10} = 11.73$ lp/cm, and $rho_{2} = 12.18$ lp/cm. It must be pointed out that the selected kernels operate below the theoretical resolution limits of the system. Albeit, these kernels reflect the best trade-off between the maximum applicable sharpness and clinically acceptable image noise in a setting for cardiac scan acquisition with requirements for superior temporal resolution based on partial scan type reconstruction.