Original Investigation

Stent Lumen Visibility in Single-energy CT Angiography: Does Tube Potential Matter?

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Abbreviations

CTA
computed tomography angiography

ALARA
as low as reasonably achievable

$CTDI_{vol}$
volumetric computed tomography dose index

Rationale and Objectives: There has been a trend toward lowering tube potential in computed tomography angiography (CTA) examinations to reduce radiation dose or contrast medium dose. The aim of this study was to evaluate the influence of tube potential on peripheral artery in-stent lumen visibility in CTA examinations.

Materials and Methods: Nine different peripheral artery stents were placed in a vessel phantom (inner diameter: 5 mm, surrounded by water) and scanned consecutively using a 128-row CT scanner with 70, 80, 100, 120, and 140 kV and two different concentrations of contrast medium to simulate contrast-enhanced blood. Medium-smooth and ultra-sharp reconstruction kernels with filtered back projection (B30f, B46f) and iterative reconstruction technique (I30f, I46f) were used. Visible in-stent lumen diameter and artifact width were evaluated using a semiautomatic software tool. All stents were scanned with digital angiography, which was regarded as the reference standard.

Results: Averaged over all stents, visible in-stent lumen diameter ranged from 1.30 ± 0.21 mm (CM2/70 kV/I30f) to 3.13 ± 0.32 mm (CM1/120 kV/I46f). In-stent lumen diameters were significantly higher for 120 and 140 kV compared to 70 kV (2.39 ± 0.73 and 2.39 ± 0.66 mm vs 1.99 ± 0.69 mm; $P = 0.01$ and $P = 0.005$). Ultra-sharp reconstruction kernels lead to significantly better in-stent lumen visibility than smooth reconstruction kernels (B46f: 2.74 ± 0.34 mm vs B30f: 1.57 ± 0.36 mm; $P < 0.001$, respectively). Furthermore, in-stent lumen visibility was improved for iterative reconstructions compared to filtered back projection (I46f: 2.93 ± 0.30 mm vs B46f: 2.74 ± 0.34 mm; $P < 0.001$). Contrast medium concentration did not influence in-stent lumen visibility.

Conclusions: Despite all known benefits of low kV CTA protocols, the use of a very low tube potential may hamper in-stent lumen visibility. A sharp kernel may be of value when evaluating the inner lumen of vascular stents.

Key Words: Imaging; Computed tomography; Stents; Phantom; Contrast medium.

INTRODUCTION

Stent-assisted angioplasty is commonly performed in peripheral and visceral artery stenosis or occlusions (1,2). Restenosis after stent implementation may occur because of intimal hyperplasia (2,3). Furthermore, stent thrombosis may occur. Therefore, evaluation of in-stent lumen can be of significant importance in patients following stent implementation.

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In clinical routine, three noninvasive methods may be used to evaluate the vascular status of the peripheral arteries: duplex ultrasound, magnetic resonance angiography, and computed tomography angiography (CTA).

Duplex ultrasound is widely available and leads to a good vascular assessment but suffers from a relevant interobserver variability (4,5). Furthermore, not all anatomic regions can be assessed using duplex ultrasound. Magnetic resonance angiography allows excellent peripheral vascular assessment, but in the presence of metallic stents magnetic field inhomogeneities might cause pseudo-stenoses or pseudo-obstructions (6). Multidetector single-energy CTA is routinely performed for assessment of peripheral and visceral arteries, and provides high sensitivity and specificity for assessment of vascular stenoses (7–9).

Initial studies on lower extremity CTA have been performed with a tube potential of 120 kV (3,8). In accordance with the “as low as reasonably achievable” (ALARA) principle, continuing efforts have been made to lower radiation and contrast medium exposure from CT. Decreasing the tube potential is especially effective in CTA because of the fact that the relative iodine attenuation increases as tube potentials approach the k-edge of iodine (33.2 keV) (10–13). Thus, tube potential has been progressively lowered in lower extremity CTA (11,12). Recent studies reported feasibility and superior image quality for 70 kV lower extremity CTA protocols (11), whereas radiation dose was reduced by 35% compared to 120 kV (11).

Vascular stents can hamper the visibility of the in-stent lumen in CTA due to beam hardening and blooming artifacts. This effect might increase with decreasing tube voltage. Several previous studies have evaluated the influence of stent materials and reconstruction kernels and parameters on stent artifacts and the resulting lumen visibility. However, to our knowledge, no comprehensive research has been performed on the impact of tube potential selection on in-stent lumen visibility in single-energy CT.

Therefore, the aim of this study was to investigate the influence of tube potential on peripheral artery stent lumen visibility in CTA and to assess the impact of various acquisition parameters.

MATERIALS AND METHODS

Study Setup

Stents and Phantom Setup

Nine different vascular stents (five self-expanding and four balloon-expandable stents; Table 1) were deployed into a polyethylene tube with an inner diameter of 5 mm and an outer diameter of 5.5 mm, mimicking a 5-mm diameter vessel. All balloon-expandable stents were dilated with a 5-mm balloon and a pressure of 8 bar. For self-expandable stents, the recommendations of the vendors were followed. Stent diameter was chosen according to the recommendations of the manufacturer. Contrast medium (Accupaque 300, iohexol, 300 mg iodine/mL, GE Healthcare, Munich, Germany) was diluted to two different concentrations: CM1 was titrated to reach 300 HU at a tube potential of 120 kV, and CM2 was titrated to 300 HU at a tube potential of 70 kV. A polyethylene phantom (23 × 22 × 30 cm) was filled with water to simulate soft tissue and was positioned parallel to the z-axis into the center of the CT scanner. Each stent-containing tube was filled with CM1, positioned into the center of the phantom along the z-axis and scanned according to the scanning protocol stated in the following. Then, the tubes were flushed with saline, filled with CM2, and scanned again. Thus, 18 different setups were examined.

Establishment of Reference Standard

Radiography was used as the reference standard to measure the true inner stent width. Each stent-containing tube was placed in the isocenter on the examination table of a high-resolution angiography system (Allura Xper, Philips Medical Systems, Best, The Netherlands) next to a calibration ruler. The tubes were placed in the same spatial orientation as in the CT examination so that the anterior–posterior radiography projection matches the horizontal measurements in the CT images. The largest possible source detector distance was used, and the tubes were placed as close to the detector as possible. Each tube was x-rayed in the highest possible resolution (diagonal detector width of 15 cm, pixel size of 0.1 × 0.1 mm). Images were calibrated using the ruler. The inner width of the stents was measured five times and averaged.

CT Scanning Parameters and Image Reconstruction

All CT scans were performed on a dual-source 128-row CT scanner (SOMATOM Definition Flash, Siemens AG, Healthcare Sector, Forchheim, Germany) operated in single source mode. Collimation was set to 128 × 0.6 mm and pitch to 0.5, with a rotation time of 0.33 s. All available tube voltage settings (70, 80, 100, 120, and 140 kV) were used. Radiation dose was adapted to our routine CT scanning protocol for peripheral CTA (volumetric computed tomography dose index [$CTDI_{vol}$] of 6 mGy), and tube current settings were adapted

TABLE 1. Stent Specifications

Name	Manufacturer	D_{nom} (mm)	Type (B/S)	Material	D_{xray} (mm)	D_{CT} (mm)	W_{CT} (mm)
LifeStent	Edwards Lifescience	6	S	Nitinol	4.6	2.45 ± 0.69	1.41 ± 0.30
Palmaz Genesis	Cordis	5	B	Steel	4.3	2.06 ± 0.66	1.46 ± 0.34
Easy Wallstent	Schneider	6	S	Cobalt-based alloy	4.4	2.27 ± 0.71	1.37 ± 0.26
Visi-Pro	EV3	6	B	Steel	4.3	2.13 ± 0.68	1.38 ± 0.26
Herculink Elite	Abbott	5	B	Cobalt-chromium alloy	3.9	1.72 ± 0.67	1.38 ± 0.27
Absolute Pro	Abbott	6	S	Nitinol	4.5	2.36 ± 0.68	1.42 ± 0.30
Omnilink Elite	Abbott	6	B	Cobalt-chromium alloy	4.3	2.04 ± 0.70	1.36 ± 0.25
Xpert	Abbott	5	S	Nitinol	4.7	2.61 ± 0.56	1.74 ± 0.48
sinus SuperFlex	Optimed	7	S	Nitinol	4.7	2.32 ± 0.69	1.39 ± 0.26

B, balloon-expandable; CT, computed tomography; D_{CT}, inner stent diameter after deployment in tube as measured by CT, averaged over all scan settings; D_{nom}, nominal diameter given by the manufacturer; D_{xray}, inner stent diameter after deployment in tube as measured using x-ray (reference standard); S, self-expandable; W_{CT}, apparent stent width after deployment in tube as measured by CT, averaged over all scan settings.