Dual-Source Dual-Energy CT Angiography of the Supra-Aortic Arteries with Tin Filter: Impact of Tube Voltage Selection

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Rationale and Objectives: Automatic bone and plaque subtraction (BPS) in computed tomographic angiographic (CTA) examinations using dual-energy CT (DECT) remains challenging because of beam-hardening artifacts in the shoulder region and close proximity of the internal carotid artery to the base of the skull. The selection of the tube voltage combination in dual-source CT influences the spectral separation and the susceptibility for artifacts. The purpose of this study was to assess which tube voltage combination leads to an optimal image quality of head and neck DECT angiograms after bone subtraction.

Materials and Methods: Fifty-one patients received tin-filter–enhanced DECT angiograms of the supra-aortic arteries using two voltage protocols: 24 patients were studied using 80/Sn140 kV and 27 using a 100/Sn140 kV protocol, both protocols with an additional tin filter. A commercially available DE-CTA BPS algorithm was used. Artificial vessel erosions in BPS maximum intensity projections (four-level Likert scale with CTA source data as reference) and vessel signal-to-noise ratio (SNR) were assessed in the level of the shoulders and the base of the skull in each patient and compared.

Results: At the level of the shoulder, 100/Sn140 kV achieved higher SNR (23.4 ± 6.4 at 80/Sn140 kV vs. 35.1 ± 11.8 at 100/Sn140 kV; $P < .0001$) with less erosions (erosion score 3.9 ± 0.4 in 80/Sn140 kV vs. 2.1 ± 1.3 in 100/Sn140 kV; $P < .0001$) than 80/Sn140 kV. At the level of the skull base, erosion scores and objective image quality of arterial segments were comparable with both protocols ($P = .14$).

Conclusions: The 100/Sn140 kV protocol achieved more favorable results for BPS of the supra-aortic arteries than the 80/Sn140 kV protocol.

Key Words: Dual-energy CTA; supra-aortic arteries; tin filter; image quality; spectral CT.

Computed tomography angiography (CTA) and magnetic resonance imaging (MRI) are the two most important imaging modalities for noninvasive angiographic studies of the supra-aortic vessels (1). A major advantage of CT over MRI is the detection of calcified plaques which is clinically relevant for risk stratification in patients with asymptomatic hemodynamically relevant internal carotid artery stenosis and for planning interventions or surgery (2). However, visibility of arterial segments is limited in regions with close contact to bones and extensive calcifications when using conventional CTA images. Furthermore, it is impossible to create angiographic-like maximum intensity projection (MIP) images from plain CT data sets because of superposition of bones and calcified plaques. Automatic bone and plaque subtraction (BPS) by dual-energy CTA (DE-CTA) has become an established method to suppress bones and calcified plaques in the final CTA image and to provide MIP reconstructions of the supra-aortic arteries similar to angiograms created by MRA (3–5). However, this technique is still limited in challenging anatomic regions such as the shoulders and at the base of the skull or in the presence of heavily calcified plaques where artificial vessel erosions may occur (6–12).

Second-generation dual-source CT systems (Somatom Definition Flash; Siemens) feature a tin filter which allows further hardening of the high energy spectrum. Thus, a combination of 100/140 kV with tin filter (100/Sn140 kV) achieves a comparable spectral separation as 80/140 kV without tin filter while providing lower noise levels in the low-energy spectrum (13–16), which may improve image

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quality in the shoulder region. On the other hand, a combination of 80/140 kV with tin filter (80/Sn140 kV) leads to a further improved spectral separation, which might improve the accuracy of BPS in the base of the skull because of a larger difference of the calcium and iodine slope. Thus, both protocols appear attractive for DE-CTA of the supra-aortic vessels, and it remains uncertain which voltage combination is optimal.

The goal of this study was to compare tin-filter–enhanced protocols for DE-CTA of the supra-aortic arteries using 80/Sn140 kV and 100/Sn140 kV in terms of subjective (vessel erosions in BPS MIPs) and objective (signal-to-noise ratio [SNR]) image quality.

MATERIAL AND METHODS

Patients

The institutional review board waived approval for this retrospective study. After switching our routine scanning protocol for DECT of the supra-aortic arteries from 100/Sn140 kV to 80/Sn140 kV, we selected the last 27 patients who were scanned with 100/Sn140 kV and the first 24 patients who were scanned with 80/Sn140 kV for retrospective evaluation. Thus, 51 unselected data sets were included into the evaluation.

CT Data Acquisition

All CT examinations were obtained on a 128-slice second-generation dual-source scanner (Somatom Definition Flash; Siemens Healthcare, Forchheim, Germany). Online tube current modulation (CareDose4D) was enabled. A tin filter was used in the high energy spectrum in both protocols (13). The 80/Sn140 kV protocol was dosewise adapted to the 100/Sn140 kV protocol. Acquisition parameters for the 80/Sn140 kV protocol were 290/145 ref. mAs and 139/139 ref. mAs for the 100/Sn140 kV protocol. Each detector was collimated to 64 × 0.6 mm with a flying focal spot. A pitch of 0.9 was applied. Rotation time was set to 0.28 seconds.

The scan range was planned from the aortic arch to the end of the skull. Iodinated contrast medium of 70 mL (400 mg iodine/mL, Imeron 400; Altana, Konstanz, Germany) were injected into a cubital vein at a flow setting of 5.0 mL/s followed by 40 mL of saline chaser at the same injection rate using a dual head injector (CT Stellant; Medrad, Indianola, PA). A scan delay of 4 seconds was used. Bolus tracking was automatically triggered at 120 Hounsfield units (HU) in the proximal ascending aorta. The scan was performed in caudocranial direction.

CT Data Reconstruction

Source images of both protocols were reconstructed with a non–edge-enhancing soft reconstruction algorithm (D30f) dedicated for DECT postprocessing. Slice thickness and increment were 0.75 and 0.5 mm, respectively. Two individual stacks of images for each detector (low- and high-kV images) and one stack of DE-mixed images were reconstructed. The latter contained weighted information from both detectors with a weighting factor of 0.6 (60% from the low-kV scan and 40% from the high-kV scan), resembling regular 120-kV images in terms of dose and image quality.

Image Postprocessing

After reconstruction, fully automatic BPS was performed without further manual adjustments to the algorithm using a workstation with dedicated commercial postprocessing software (Syngo MMWP, VE31A). It combines DECT information (ratio of HUs at the different tube voltages) and an automatic segmentation algorithm to discriminate calcium from iodine and creates images where all pixels containing calcium are assigned a HU of −1024. These resulting BPS data sets were stored. Commercially available image processing software (Syngo; Siemens Medical Solutions, Forchheim, Germany) was used to create axial multiplanar reformations (MPR, slice thickness 3 mm) from the DE-mixed images (CT source images) and freely rotatable multi-intensity projection images (3D-MIP) after BPS using standard settings.

Quantitative Image Analysis

The assessment of SNR was performed by a board-certified, subspecialty-certified reader with 6 years of training in neuroradiology. For all axial MPRs, regions of interest (ROIs) were placed in the proximal brachiocephalic trunk (BT) and in the internal carotid artery (ICA) where it is embedded in the skull base (C2–C6 segments). All ROI measurements were repeated in three consecutive slices and averaged. Signal was defined as CT density in HU, image noise as standard deviation (SD) of attenuation within an ROI. SNR was calculated using the following standard equation: SNR = (mean HU of tissue in ROI)/(SD of HU in ROI).

Qualitative Image Analysis

Qualitative analysis of images was independently performed by two board-certified, subspecialty-certified readers with 4 and 6 years of training in neuroradiology, respectively. All images were reviewed at a PACS workstation (Centricity; GE Healthcare). As criterion for image quality, artificial vessel erosions in 3D-MIP data sets after BPS were graded using a four-item score: 1 (absence of artificial narrowing of the vessel lumen), 2 (<50% artificial narrowing), 3 (>50% artificial luminal narrowing) and 4 (complete vessel gap/pseudo-occlusion). Axial CTA source data (3-mm MPR) served as reference. The following supra-aortic segments were assessed independently: BT, subclavian artery (SA), common carotid artery (CCA), segments C2–C7 of