European Journal of Radiology 85 (2016) 720–725

Contents lists available at ScienceDirect

European Journal of Radiology

journal homepage: www.elsevier.com/locate/ejrad

Carotid dual-energy CT angiography: Evaluation of low keV calculated monoenergetic datasets by means of a frequency-split approach for noise reduction at low keV levels

Philipp Riffel[a,*], Holger Haubenreisser[a], Mathias Meyer[a], Sonja Sudarski[a], John N. Morelli[b], Bernhard Schmidt[c], Stefan O. Schoenberg[a], Thomas Henzler[a]

[a] Institute of Clinical Radiology and Nuclear Medicine, University Medical Center Mannheim, Medical Faculty Mannheim—Heidelberg University, Mannheim, Germany
[b] St. John's Medical Center, Tulsa, OK, United States
[c] Siemens AG, Healthcare Sector, Forchheim, Germany

ARTICLE INFO

Article history:
Received 25 June 2015
Received in revised form 14 January 2016
Accepted 18 January 2016

Keywords:
Dual energy CT
Calculated monoenergetic low keV images
Frequency-split technique

ABSTRACT

Background and purpose: Calculated monoenergetic ultra-low keV datasets did not lead to improved contrast-to-noise ratio (CNR) due to the dramatic increase in image noise. The aim of the present study was to evaluate the objective image quality of ultra-low keV monoenergetic images (MEIs) calculated from carotid DECT angiography data with a new monoenergetic imaging algorithm using a frequency-split technique.

Materials and methods: 20 patients (12 male; mean age 53 ± 17 years) were retrospectively analyzed. MEIs from 40 to 120 keV were reconstructed using the monoenergetic split frequency approach (MFSA). Additionally MEIs were reconstructed for 40 and 50 keV using a conventional monoenergetic (CM) software application. Signal intensity, noise, signal-to-noise ratio (SNR) and CNR were assessed in the basilar, common, internal carotid arteries.

Results: Ultra-low keV MEIs at 40 keV and 50 keV demonstrated highest vessel attenuation, significantly greater than those of the polyenergetic images (PEI) (all p-values <0.05). The highest SNR level and CNR level was found at 40 keV and 50 keV (all p-values <0.05). MEIs with MFSA showed significantly lower noise levels than those processed with CM (all p-values <0.05) and no significant differences in vessel attenuation ($p > 0.05$). Thus MEIs with MFSA showed significantly higher SNR and CNR compared to MEIs with CM.

Conclusion: Combining the lower spatial frequency stack for contrast at low keV levels with the high spatial frequency stack for noise at high keV levels (frequency-split technique) leads to improved image quality of ultra-low keV monoenergetic DECT datasets when compared to previous monoenergetic reconstruction techniques without the frequency-split technique.

1. Introduction

The prospective acquisition of low kVp datasets in cardiovascular CT examinations is currently under intensive investigation due to the advent of CT systems utilizing kVp as low as 70 while maintaining sufficient photon output [1–3]. Although low kVp imaging increases attenuation of vascular structures due to the mean photon energy moving closer to the k-edge of iodine (33 keV), the technique has only been evaluated for cardiovascular CT [4–6], potentially limiting the accuracy of the technique for evaluation of non-vascular findings. Dual-energy CT (DECT) allows for reconstruction of standard 120 kV polyenergetic images (PEI), virtually calculated monoenergetic images up to 190 keV for metal artifact

Abbreviations: DECT, dual-energy CT; PEI, polyenergetic image; MEI, monoenergetic image; CNR, contrast-to-noise ratio; SNR, signal-to-noise ratio; MFSA, monoenergetic frequency split approach; CM, conventional monoenergetic software application.

* Corresponding author at: Institute of Clinical Radiology and Nuclear Medicine, University Medical Center Mannheim, Medical Faculty Mannheim—University Heidelberg, Theodor-Kutzer-Ufer 1-3, 68167 Mannheim, Germany. Fax: +49 621 383 3817.
E-mail address: Philipp.Riffel@umm.de (P. Riffel).

http://dx.doi.org/10.1016/j.ejrad.2016.01.015

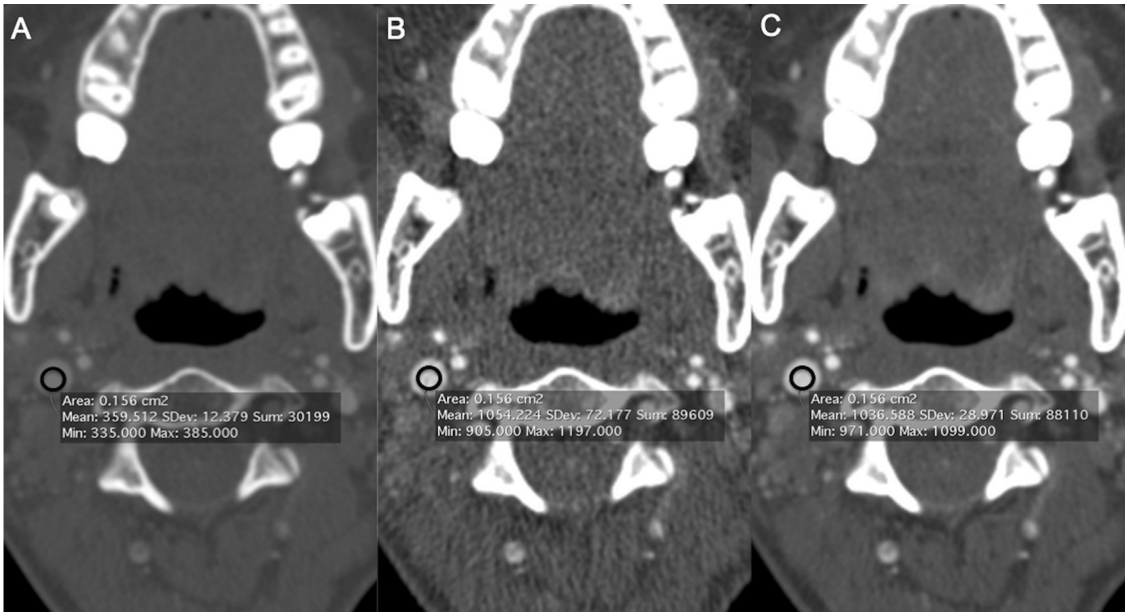

Fig. 1. Axial slices of a dual-source dual-energy CTA of the neck. 120-kV polyenergetic image (PEI) (A) is shown in comparison to monoenergetic images (MEIs) at 40 keV with CM (B) and MEIs at 40 keV with MSAF (C). A ROI is drawn within the right common carotid artery.

reduction, and low keV datasets down to 40 keV for improved vessel attenuation. Thus DECT may be a useful alternative to prospectively utilizing low kVp X-ray tube settings [7–11]. At low calculated monoenergetic keV levels, attenuation of materials with a high atomic number, such as iodine, significantly increases. Previous studies have demonstrated that calculated low keV monoenergetic datasets from DECT angiography can significantly improve contrast-to-noise ratio (CNR) when compared to PEI [12,13]. However, image noise is also increased in these images to the extent where even higher iodine contrast doses, do not substantially CNR when ultra-low keV settings are utilized [13–15]. For carotid angiography, the optimal energy level has been determined to be 60 keV [13], whereas ultra-low monoenergetic keV datasets with keV below 60 do not lead to improved CNR due to the dramatic increase in image noise at ultra-low keV levels. Recently, a so called frequency split approach has been introduced which utilizes an image reconstruction algorithm that enables increased iodine contrast at low keV levels without increased image noise [16]. Using that approach, hybrid images can be calculated where the contrast information (e.g., high attenuation of iodine in vessels) comes from the low spatial frequencies for the desired keV image, whereas the noise information (e.g., noise of surrounding tissue) is taken from a keV image at medium energy/keV level [16].

The aim of the present study was to evaluate the objective image quality of ultra-low keV monoenergetic datasets calculated from carotid DECT angiography data using a frequency split approach.

2. Materials and methods

2.1. Study population

The institutional review board waived the requirement of informed patient consent for this retrospective study. Information gathered on this population was performed in compliance with HIPAA (Health Insurance Portability and Accountability Act) guidelines. The study population consisted of 20 patients (12 male; mean age 53 ± 17 years) who underwent carotid DECT angiography and have been previously described in Ref. [13]. DECT angiographic studies of the neck were performed for clinical suspicion of vessel occlusion or dissection. No further selection of the patient collective was conducted.

2.2. Image acquisitions

All CT examinations were performed using a 64-slice dual source CT system in dual-energy mode (SOMATOM Definition; Siemens Healthcare Sector, Forchheim, Germany). Scanning parameters were kept constant for all examinations. Iodinated contrast medium (Iomeprol 400 mg I/mL, Imeron 400; Bracco Imaging S.p.A., Milan, Italy) was automatically injected through an 18-gauge intravenous antecubital catheter by using a dual-head injector (Stellant D CT Injection System Medrad Inc., Warrendale, PA). Scan initiation was determined by bolus tracking using a dedicated software application (CARE bolus Siemens Healthcare Sector, Forchheim, Germany) with the region of interest (ROI) placed in the aorta and a trigger threshold of 100 Hounsfield units (HU). Data were acquired in a caudocranial direction using the following CT parameters: pitch factor 0.6; increment 1.0; collimation 14 × 1.2 mm; reconstructed slice thickness 1.0 mm; field of view 380 mm; tube A voltage 140 kV and current 60 mAs; tube B voltage 80 kV and current 270 mAS (CARE Dose4D; Siemens Healthcare Sector); 64 slices per rotation; rotation time of 0.5 s. DECT data were transferred to a multimodality workstation (Syngo MMWP VA 21 A; Siemens Healthcare Sector).

2.3. Image reconstruction

DECT raw data were reconstructed using a medium-sharp convolution kernel D30f (Siemens Healthcare Sector, Forchheim, Germany) with a slice thickness of 1.0 mm. DECT data from 80 and 140 keV were used to reconstruct 120-kVp PEI with a slice thickness of 1 mm using 30% data from the low-kV B tube and 70% from the high-kV A tube. The images were then transferred to a multi-modality workstation (Syngo.via, Version VA30, Siemens Healthcare Sector, Forchheim, Germany) for further processing and all subsequent measurements. The DE data was processed using a novel monoenergetic frequency **s**plit approach (MFSA) for image noise reduction at ultra-low keV MEI (mono+, Siemens Healthcare Sector, Forchheim, Germany). MEI images were