Original Investigation

Image Quality on Dual-energy CTPA Virtual Monoenergetic Images: Quantitative and Qualitative Assessment

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Rationale and Objectives: This study aims to determine the optimal photon energy for image quality of the pulmonary arteries (PAs) on dual-energy computed tomography (CT) pulmonary angiography (CTPA) utilizing low volumes of iodinated contrast.

Materials and Methods: The study received institutional review board exemption and was Health Insurance Portability and Accountability Act compliant. Adults (n = 56) who underwent dual-energy CTPA with 50–60 cc of iodinated contrast on a third-generation dual-source multidetector CT were retrospectively and consecutively identified. Twelve virtual monoenergetic kiloelectron volt (keV) image data sets (40–150 keV, 10-keV increments) were generated with a second-generation noise-reducing algorithm. Standard regions of interest were placed on main, right, left, and right interlobar pulmonary arteries; pectoralis muscle; and extrathoracic air. Attenuation [mean CT number (Hounsfield unit, HU)], noise [standard deviation (HU)], signal to noise (SNR), and contrast to noise ratio were evaluated. Three blinded chest radiologists rated (from 1 to 5, with 5 being the best) randomized monoenergetic and weighted-average images for attenuation and noise. $P < .05$ was considered significant.

Results: Region of interest mean CT number increased as keV decreased, with 40 keV having the highest value ($P < .001$). Mean SNR was highest for 40–60 keV ($P < .05$) (14.5–14.7) and was higher ($P < .05$) than all remaining energies (90–150 keV) for all vessel regions combined. Contrast to noise ratio was highest for 40 keV ($P < .001$) and decreased as keV increased. SNR was highest at 60 and 70 keV, only slightly higher than 40–50 keV ($P < .05$). Reader scores for 40–50 keV were greater than other energies and weighted-average images ($P < .05$).

Conclusions: Kiloelectron volt images of 40–50 keV from the second-generation algorithm optimize attenuation on dual-energy CTPA and can potentially aid in interpretation and avoiding nondiagnostic examinations.

Key Words: Monoenergetic; monochromatic; dual-energy CT; CT pulmonary angiography; pulmonary embolism.

INTRODUCTION

Computed tomography (CT) pulmonary angiography (CTPA) is now the first-line imaging examination for the diagnosis of pulmonary embolism. Although image quality continues to improve over time, suboptimal contrast enhancement of the pulmonary arteries on CTPA occasionally occurs, resulting in difficult image interpretation and nondiagnostic studies.

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Dual-energy CT (DECT) imaging generates both low- and high-energy CT data. Dual-energy imaging on a dual-source CT scanner entails two x-ray CT tubes, one using a low and the other a high kilovolt potential (kVp), that image in a simultaneous or near-simultaneous manner (1,2). Each of the resulting two x-ray beams are composed of x-ray photons of varying photon energies, expressed in kiloelectron volts (keV), with the highest photon keV approximating that of the kVp used for imaging. Lower-energy photons are more likely to have photoelectric interactions with high atomic number elements such as iodine, given that the energies of these photons are closer to the k-shell electron binding energy of iodine (33 keV). Thus, iodine has more interactions with photons and hence has higher attenuation at lower photon energies than at higher photon energies. Therefore, the concentration of iodine in a region may be inferred from the change in CT numbers between low- and high-energy data. Additionally, virtual monoenergetic images may be synthesized as if an image was acquired using an x-ray beam composed of a single photon energy (3–5).

Knowledge of the optimal monoenergetic image photon energy is needed (1). Pulmonary artery attenuation is higher on lower-energy virtual monoenergetic images, given the greater contribution of the lower energy image data. Derived images however can be noisier. Previous studies have primarily evaluated pulmonary artery enhancement on CTPA studies using a second-generation dual-source, dual-energy imaging protocol with 80 and 140 kVp (2,3) and a first-generation monoenergetic algorithm (4,5). Currently, a new second-generation monoenergetic algorithm (6–14) is available that can further reduce image noise and for which the optimal monoenergetic keV has yet to be determined (14). Although investigated, only one study by Meier et al. specifically evaluated DECT for pulmonary angiography using the second-generation monoenergetic algorithm for optimal keV (14), and a recent second study evaluated 40 keV in diagnostic accuracy for pulmonary embolism (15). Dual-energy CTPA is able to be performed with low intravenous contrast volumes on the order of 50 cc and smaller (5,11,16–18).

Therefore, the purpose of this study was to determine the optimal photon energy for image quality of the pulmonary arteries on dual-energy CTPA utilizing low volumes of iodinated contrast.

MATERIALS AND METHODS

Subjects

This retrospective study received an institutional review board exemption and was Health Insurance Portability and Accountability Act compliant. Adult outpatients over age 18 years who had been imaged for clinical purposes using a departmental dual-energy CTPA protocol on a third-generation 192 detector-row configuration, dual-source multidetector CT (Force, Siemens Healthineers, Forchheim, Germany) between December 2014 and April 2015 were retrospectively selected. A computer word search of radiology reports for the term "pulmonary angiogram" in the technique section and limited to studies performed on the specific dual-source CT was conducted. All clinical CTPAs on this CT scanner are performed using a standard dual-energy protocol. Of the 94 patients who had dual-energy CTPAs during this time period, those who had studies with unavailable data ($n = 31$) such as low and high kVp data sets archived in the picture archiving and communication system (PACS) or deviation from the standard protocol used for DECT ($n = 7$) were excluded. Subsequently, 56 (36 women, 20 men) had complete data and were included in the study. Mean ± standard deviation (SD) age was 57.7 ± 18 years (range 20–97 years) for women and 58 ± 17.9 years (range 20–97 years) for men ($P = .26$).

CT Imaging Protocol

The departmental clinical dual-energy CTPA protocol employed imaging in dual-source mode using tube voltages of 90 kVp (A tube) and 150 kVp (B tube) with quality reference milliampere seconds (mAs) of 130 mAs (A tube) and 100 mAs (B tube), respectively. Tube current modulation (CareDose4D) was utilized. The gantry rotation time was 250 milliseconds, and the detector-row configuration was 192 × 0.6 mm. Patients received 50–60 cc of nonionic contrast (Iopromide 300 mgI/mL; Bayer Healthcare, Whippany, NJ) that was injected intravenously at a rate of 3–5 cc/s and followed by a saline bolus of 30 cc. Bolus tracking was used with the region of interest (ROI) placed over the main pulmonary artery (MPA) proximal to the bifurcation of right (RPA) and left (LPA) pulmonary arteries and a Hounsfield unit (HU) threshold of 130 was used for automatic triggering. Images were obtained in the caudocranial direction following instructions to the patient to take a "small breath in and hold."

Image data were reconstructed in 1-mm axial sections at 0.8-mm intervals using a standard field of view and a 512 × 512 matrix. Iterative reconstruction (Advanced Modeled Iterative Reconstruction, ADMIRE, strength 2) was used for reconstruction. Low and high kVp data were reconstructed using Qr40 kernel for material decomposition and dual-energy data analysis. A soft-tissue kernel (Br40) was utilized for reconstruction of weighted-average (mixed) images with a weighting factor of 0.6, meaning 60% of 90 kVp and therefore 40% of 150 kVp image data were combined to form each mixed image.

Dual-energy Data Analysis

Image data were anonymized (HP). For each patient, 12 virtual monoenergetic kiloelectron volt (keV) data sets were generated from the dual-energy data in 10 keV increments from 40 to 150 keV using a second-generation virtual monoenergetic algorithm (Virtual Monoenergetic Plus, *Syngo.via*, VA30, Siemens Healthineers). Each data set was exported as a series for image analysis. The CT dose index and dose length product (DLP) were recorded. The effective dose was calculated by multiplying DLP by a conversion factor of 0.014 mSv/(mGy^{-1} cm^{-1}) as measured in a 32-cm phantom (19,20).

Quantitative Analysis

Images were viewed on a workstation using a DICOM viewer (*Syngo.via*) by a fourth-year radiology resident (BD) who placed ROI of standard sizes on the images. For each patient, attenuation [mean CT number (mean HU)] and image noise [CT number standard deviation (HUSD)] were measured with ROIs (size) placed in the MPA (1.5 cm^2 ROI), RPA (1 cm^2 ROI), LPA (1 cm^2 ROI), and right interlobar pulmonary arteries (0.5 cm^2 ROI); pectoralis major muscle (0.5 cm^2 ROI);