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Research article

Influence of spectral detector CT based monoenergetic images on the computer-aided detection of pulmonary artery embolism

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ABSTRACT

Objective: To evaluate the influence of monoenergetic reconstructions using a spectral detector CT (SDCT) on the computer aided detection (CAD) of pulmonary artery embolism (PAE) on CT pulmonary angiography (CTPA) and CT in venous contrast phase (CTV).

Material and Methods: A retrospective data base search identified 15 patients with CTPA and 18 patients with CTV and diagnosis of PAE. For these patients, monoenergetic (monoE) images at different energy levels or with a fixed attenuation in the pulmonary artery were generated and independently analyzed using a commercially available computer aided detection (CAD) tool. Attenuation in the pulmonary artery and in the embolus was measured.

Results: For CTPA and CTV, in monoenergetic images the difference in attenuation between vessel and embolus was significantly higher than in conventional images. In CTPA the detection rate was highest in the > 500 HU monoE images with 67,9% detected emboli and 93,3% of patients correctly identified as having PAE. At the same time the false positive rate could be significantly reduced by using monoE images compared to conventional images.

Detection rates for CTV were lower than in CTPA but were raised significantly by monoE reconstructions.

Conclusions: The combination of SDCT and CAD improves the diagnostic accuracy of CAD and enables CAD interpretation of CTV.

1. Introduction

Pulmonary artery embolism (PAE) is one of the main differential diagnoses in patients presenting with chest pain and/or dyspnea and ranks as the third most common cause of death from cardiovascular disease, after myocardial infarction and stroke [1]. CT pulmonary angiography (CTPA) has evolved as the reference standard for the diagnosis of PAE [2] and improvements in CT technology especially the widespread adoption of multi-detector CT and more recently the increasing use of dual-energy CT (DECT) have led to an improved diagnostic accuracy and an increase in the detection of small subsegmental emboli [3–5]. Peripheral pulmonary artery emboli are also a frequent incidental finding in patients undergoing chest CT for reasons other than suspected PAE with rates of approximately 1.0–1.5% for all patients and 4.0 −5.0% for inpatients [6]. Patients undergoing CT for other reasons than suspected PAE are often examined using a venous contrast phase which limits the ability to detect smaller subsegmental emboli. The use of virtual monoenergetic images at lower kiloelectron volt settings (keV) derived from DECT allows an enhancement of vessel attenuation [7] and thereby improves the detection rate of pulmonary emboli in these patients [8].

The increasing use of CT imaging for emergency room patients [9,10], including CTPA studies, adds to the considerable workload of radiologists. With the assessment of the entire pulmonary artery tree for small emboli remaining a time consuming task, the provision of prompt and accurate diagnoses presents a significant challenge [11,12]. Computer-aided detection tools are increasingly available for a wide array of indications including PAE and aim at assisting radiologist in providing timely diagnoses. They may reduce the number of missed lesions and thereby increase diagnostic certainty and accuracy [13].

Recently the IQon CT (Philips, Best, The Netherlands), the first commercially available dual layer CT/spectral detector CT scanner (SDCT) became available, which offers a new approach to DECT. Instead of using a tube-based approach the scanner uses a single x-ray

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source but a detector with two layers that simultaneously acquire low- and high-energy data [14]. This has the advantage of always acquiring spectral data sets and thus enabling retrospective data analysis.

The aim of our study was to employ this SDCT for the evaluation of the pulmonary artery, to combine the benefits of DECT and CAD analysis and evaluate the influence of different monoenergetic reconstructions of CT examinations on the diagnostic performance of a CAD tool dedicated at the detection of peripheral pulmonary emboli.

2. Material and methods

Approval for this study was waived by the institutional ethics committee because of the retrospective nature of the presented analysis.

2.1. Patient population

We conducted a retrospective data base search for patients with the diagnosis of PAE who underwent either a CTPA or a CT with venous contrast phase (CTV) on the spectral detector CT (SDCT, IQon, Philips Healthcare, Best, The Netherlands) at our institution in the first 6 months since its installation (July 2016–December 2016). The search identified 15 patients with CTPA and 18 patients with CTV with a diagnosis of PAE.

2.2. Image acquisition and reconstruction

CT data were acquired on a 128–row spectral detector CT (IQon, Philips Healthcare, Best, The Netherlands).

For CTPA exams, 60 ml of contrast media (300 mg Iodine/ml, Accupaque 300, GE Healthcare, Braunschweig, Germany) followed by a 40 ml NaCl flush were injected intravenously at a flow rate of 4 ml/s. Scanning was initiated once the attenuation in the main pulmonary artery (MPA) reached a threshold of 150 HU with a subsequent delay of 11 s. Scanning parameters were: slice collimation of 0.625 mm, rotation time 0.33 s, tube potential 120 kV. Automatic tube current modulation was used. Spectral base image (SBI) datasets were reconstructed to an axial slice thickness of 1 mm and an overlap of 0.5 mm on a 512 × 512 pixel matrix.

For CTV 100 ml of contrast media (300 mg Iodine/ml, Accupaque 300, GE Healthcare, Braunschweig, Germany) were injected intravenously followed by a 25 ml NaCl flush using a flow rate of 2–3 ml/s. Scanning was started 60 s after a threshold of 150 HU in the descending aorta was reached. Scanning parameters for CTV were: slice collimation 0.625 mm, rotation time 0.5 s, tube potential 120 kV. Automatic tube current modulation was used. SBI datasets were reconstructed to an axial slice thickness of 2 mm and an overlap of 1 mm on a 512 × 512 pixel matrix.

SBI datasets were used to reconstruct conventional and monoenergetic (monoE) images on an offline workstation (Intellispace Portal, Philips Healthcare). For the conventional images, a statistical iterated reconstruction algorithm (Philips iDose^4 level 2) was used while for monoE images a comparable statistical iteration algorithm (Philips Spectral) was used. MonoE images were generated for 70 keV, 40 keV and at levels that resulted in an attenuation of the main pulmonary artery (MPA) of just above 400, 500 and 600 HU (> 400 HU, > 500 HU, > 600 HU). Exemplary images of CTPA and CTV examinations in different monoE reconstructions are depicted in Figs. 2–4.

Additionally, CTPA datasets were reconstructed for the > 500HU monoE level to an axial slice thickness of 2 mm and an overlap of 1 mm to allow for evaluation of the influence of slice thickness on PAE detection rate.

2.3. Image analysis

Attenuation in the MPA was measured using a region of interest (ROI), which was positioned immediately proximal to the pulmonary bifurcation and sized to the maximum extent possible. Attenuation of the embolus was measured using a ROI positioned in the most substantial part of the embolus. Difference of mean attenuation between vessel and embolus was calculated for each patient and each reconstruction.

Complete patient datasets were evaluated for pulmonary embolism by an experienced radiologist (over 3 years of experience in thoracic radiology) who had access to all reconstructions, could also view previous and follow-up studies if existent and correlated his findings with the written clinical report signed by two different radiologists. Emboli were counted for the different pulmonary lobes and were differentiated between segmental and subsegmental localizations. Emboli were counted as multiple findings when there was no continuous connection between different parts of the embolus. The results of this assessment formed the ground truth.

2.4. CAD analysis

The different monoE and conventional images were analyzed using a dedicated, commercially available CAD tool for the detection of PAE (Pulmonary Artery Assessment, PAA, Intellispace Portal, Version 9, Philips Healthcare, Best, The Netherlands). The tool segments the segmental and subsegmental pulmonary vasculature (the main pulmonary artery and the central parts of the left and right pulmonary artery are not segmented by the tool) and detects differences in attenuation between the vessel and an embolus (see Fig. 5 for a depiction of the CAD analysis). Correct positive detections were counted for the different pulmonary lobes and separated in segmental und subsegmental emboli. Redundant detections of the same embolus were ignored. Furthermore, false positive findings were noted. The percentage of detected emboli was calculated as compared to ground truth. Moreover, the percentage of patients with at least one correctly detected embolus was calculated for each reconstruction.

2.5. Statistical analysis

SPSS Statistics 24 (IBM Corporation, Armonk, USA) was used for statistical analysis. Variables were tested for normal distribution using the Shapiro-Wilk-test and normal distribution was rejected. Significance of differences was calculated using the Wilcoxon signed-rank test. For comparison between CTPA and CTV the Mann-Whitney-U test was used. Levels of significance are stated as * = $p < 0.05$; ** = $p < 0.005$;*** = $p < 0.001$.

3. Results

3.1. Attenuation measurements

Attenuation of the MPA in the conventional images ranged from 211 HU to 500 HU with a mean attenuation of 357 ± 90 HU for CTPA. While mean attenuation was significantly lower in CTV ($p < 0.001$), the attenuation range was narrower in CTV (114–205 HU) with a mean of 162 ± 29 HU. In patients with CTPA, reconstructions were possible at all attenuation levels (> 400 HU, > 500 HU, > 600 HU), whereas in patients with CTV a monoE reconstruction with an attenuation of > 600 HU in the MPA was possible in only one patient, a > 500 HU monoE reconstruction was possible in 56% of patients and a > 400 HU monoE reconstruction was possible in 61%.

Mean attenuation in the MPA of all patients was significantly higher in most monoE images than in conventional images except for the > 400 HU monoE in CTPA where the mean attenuation was only slightly but not significantly higher than in the conventional images and the exception of the > 600HU monoE in CTV, which was only possible in one patient (see Table 1).

Compared to attenuation values in conventional images of CTPA, in CTV contrast attenuation in the MPA was significantly higher in monoE