Original Investigation

Regional Distribution of Pulmonary Blood Volume with Dual-Energy Computed Tomography: Results in 42 Subjects

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Rationale and Objectives: The noninvasive approach of lung perfusion generated from dual-energy computed tomography acquisitions has entered clinical practice. The purpose of this study was to analyze the regional distribution of iodine within distal portions of the pulmonary arterial bed on dual-source, dual-energy computed tomography examinations in a cohort of subjects without cardiopulmonary pathologies.

Materials and Methods: The study population included 42 patients without cardiorespiratory disease, enabling quantitative and qualitative analysis of pulmonary blood volume after administration of a 40% contrast agent. Qualitative analysis was based on visual assessment. Quantitative analysis was obtained after semiautomatic division of each lung into 18 areas.

Results: The iodine concentration did not significantly differ between the right (R) and left (L) lungs ($P = .49$), with a mean attenuation of 41.35 Hounsfield units (HU) and 41.14 HU, respectively. Three regional gradients of attenuation were observed between: (a) lung bases and apices ($P < .001$), linked to the conditions of examination (mean Δ: 6.23 in the R lung; 5.96 in the L lung); (b) posterior and anterior parts of the lung ($P < .001$) due to gravity (mean Δ: 11.92 in the R lung ; 15.93 in the L lung); and (c) medullary and cortical lung zones ($P < .001$) (mean Δ: 9.35 in the R lung ; 8.37 in the L lung). The intensity of dependent-nondependent ($r = 0.42$; $P < .001$) and corticomedullary ($r = 0.58$; $P < .0001$) gradients was correlated to the overall iodine concentration.

Conclusion: Distribution of pulmonary blood volume is influenced by physiological gradients and scanning conditions.

Key Words: Dual-energy computed tomography; lung perfusion; gravity; pulmonary arteries; CT angiography.

INTRODUCTION

Since the introduction of dual-energy computed tomography (DECT) in clinical practice, great interest has been directed toward analysis of the distribution of iodine in the most distal parts of the pulmonary circulation, often referred to as perfusion imaging. Initially only available with dual-source CT, DECT has become accessible to single-source CT, with the introduction of rapid kilovolt switching and more recently, dual-layer (sandwich) detectors. Regardless of the difference in the technological approach, perfusion images are generated from the same data set as that used for morphologic evaluation, offering the possibility of a simultaneous approach of structure and function in respiratory patients (1,2). This combined information provided with CT is a major advantage over scintigraphy and magnetic resonance imaging, not only in the field of primary disorders of the pulmonary circulation, such as acute pulmonary embolism (3–7), but also in the context of bronchopulmonary diseases where perfusion alterations can be interpreted with precise knowledge of the underlying morphologic changes (8–13). More recently, this complementarity has also been extended in the field of chronic thromboembolic disease and pulmonary hypertension (14–17), while a growing interest is reported in oncologic indications (18,19).

The common denominator for these clinical applications is the detection of hypoperfused areas, which may vary from large defects to more subtle perfusion alterations. In the context of smoking populations, depiction of vascular alterations preceding smoking-related emphysema has been reported as a new functional phenotype that could help differentiate smokers with and without emphysema susceptibility (20,21). Because the role of imaging as a tool for investigating lung physiology is growing at an accelerating pace (22), the noninvasive approach offered by DECT suggests that this technique might play a greater role in the near future. With these

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expectations in mind, it appears necessary to improve our knowledge of lung perfusion in normal subjects that could serve as a basis for future investigations in respiratory disorders. Among these physiological considerations, gravitational gradients in perfusion are well known, with flow determined on the basis of differences in pulmonary alveolar, pulmonary arterial, and pulmonary venous pressures (23). There are also differences in perfusion that exist in the horizontal plane independent of the effects of gravity, with a stratified distribution of perfusion found to decrease from the central region of the lung to its periphery (24). Mainly described with single-photon emission computed tomography imaging, these flow gradients have not been specifically investigated on DECT perfusion images. Because lung perfusion analysis does not only rely on morphologic changes but also integrate quantitative measures, it is important to take into account the well-known physiological changes of lung perfusion when interpreting the subjective and objective regional information of DECT lung perfusion images. The purpose of the present study was thus to evaluate the detectability of regional changes in the distribution of pulmonary perfusion on dual-source, dual-energy chest CT examinations in a cohort of subjects without cardiopulmonary pathologies.

MATERIALS AND METHODS

Study Population

Eligibility to this study required the fulfillment of the following criteria: (a) no smoking history; (b) absence of respiratory disease after a diagnostic workup, including a dual-source, dual-energy chest CT angiographic (DE-CTA) examination, (c) rated with an excellent image quality (ie, attenuation >180 Hounsfield units (HU) in central pulmonary arteries; no respiratory motion artifacts); and (d) obtained on the same CT unit. The latter criterion was chosen to perform quantitative lung perfusion analysis from examinations obtained with similar CT technology, thus avoiding potential differences linked to changes over time in DECT technology. At the time of this investigation, the up-to-date dual-source CT technology was that available on a second-generation dual-source CT scanner, restricting our selection to patients scanned on this CT scanner.

Over a 2-year-period, 42 consecutive patients fulfilled these criteria. The clinical indications for DE-CTA included the evaluation of mild dyspnea, related to deconditioning after the diagnostic workup ($n = 30$), suspicion of abnormal chest radiograph ($n = 8$), and family screening for hereditary hemorrhagic telangiectasia ($n = 4$). The study protocol was approved by our institutional Ethics Committee with waiver of patient's informed consent according to national regulations.

CT Evaluation

Scanning Parameters

DE-CTA examinations were performed on a second-generation dual-source CT system (Somatom Definition Flash; Siemens Healthcare, Forchheim, Germany). A combination of a tin-filtered (Sn) 140 kVp (tube B) and 80 kVp (tube A) was used, with a tube current set at 100 mAs and 300 mAs respectively; the automatic modulation of the milliamperage was not activated. The collimation was set at 32×0.6 mm with a z-flying spot, enabling reconstruction of 64 slices per rotation. The rotation time was 0.28 seconds with a pitch value of 0.5. Acquisition was performed after a deep inspiration in the caudocranial direction, with all patients installed in the supine position. The injection was performed via an antecubital vein, with administration of 80 mL of a 40% contrast agent (Iomeron [iomeprol], Bracco Imaging, Patheon Italia SPA, Ferentino Italy) followed by 40 mL of a diluted contrast agent (70% NaCl; 30% of iodine). Data were acquired using a bolus-tracking technique with a threshold of 120 HU in the ascending aorta.

Image Reconstruction

From each dataset, three series of images were reconstructed: (a) diagnostic lung and mediastinal images, corresponding to averaged images of both tubes with a ratio of 0.6 (60% from tube A; 40% from tube B); these images consisted of contiguous 1-mm thick transverse CT sections, reconstructed with a soft (B20f) and sharp (B50f) kernel for mediastinal and lung images, respectively. Iodine distribution maps, further referred to as perfusion images, were generated by specific, FDA-approved DE postprocessing software (DE lung pulmonary blood volume [PBV], Siemens Healthcare) on a dedicated postprocessing workstation ("Lung PBV" in syngo Dual Energy; Siemens Healthcare). Lung perfusion information was coded using a gray scale.

CT Parameters Analyzed

- *For each examination*, we recorded the z-axis coverage, the duration of data acquisition, the heart rate (bpm), the patient's height (cm), and weight (kg) for the purpose of subsequent calculation of the body mass index (kg/m^2) and the dose-length-product (mGy·cm) with calculation of the effective radiation dose using a conversion factor for chest CT of 0.0147 mSv/mGy·cm.
- *On mediastinal images*, we measured the level of attenuation within the pulmonary trunk, the right and left main pulmonary arteries, the anterior segmental artery of the right upper lobe (RA1) and posterior segmental artery of the right lower lobe (RA10), the left atrium, and ascending aorta.
- *On perfusion images*, we did the following:

We recorded the presence and severity of artifacts due to highly concentrated contrast medium that could be seen alone, in the upper lung zones around systemic veins, or mixed with cardiac pulsation artifacts around the cardiac cavities. Artifact analysis was recorded at a segmental level using the Boyden nomenclature (25) (score 0: no artifacts; score 1: mild; score 2: moderate; score 3: severe artifacts). Artifacts rated as moderate or severe were considered as partially or totally altering perfusion analysis in the corresponding segments.