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Emphysema quantification and lung volumetry in chest X-ray equivalent ultralow dose CT – Intra-individual comparison with standard dose CT

Michael Messerli [a,b,*], Thorsten Ottilinger [b], René Warschkow [c], Sebastian Leschka [b,d], Hatem Alkadhi [d], Simon Wildermuth [b], Ralf W. Bauer [b]

[a] Department of Nuclear Medicine, University Hospital Zurich, University Zurich, Switzerland
[b] Division of Radiology and Nuclear Medicine, Cantonal Hospital St. Gallen, Switzerland
[c] Department of Surgery, Cantonal Hospital St. Gallen, Switzerland
[d] Institute of Diagnostic and Interventional Radiology, University Hospital Zurich, University Zurich, Switzerland

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ABSTRACT

Objectives: To determine whether ultralow dose chest CT with tin filtration can be used for emphysema quantification and lung volumetry and to assess differences in emphysema measurements and lung volume between standard dose and ultralow dose CT scans using advanced modeled iterative reconstruction (ADMIRE).

Methods: 84 consecutive patients from a prospective, IRB-approved single-center study were included and underwent clinically indicated standard dose chest CT (1.7 ± 0.6 mSv) and additional single-energy ultralow dose CT (0.14 ± 0.01 mSv) at 100 kV and fixed tube current at 70 mAs with tin filtration in the same session. Forty of the 84 patients (48%) had no emphysema, 44 (52%) had emphysema. One radiologist performed fully automated software-based pulmonary emphysema quantification and lung volumetry of standard and ultralow dose CT with different levels of ADMIRE. Friedman test and Wilcoxon rank sum test were used for multiple comparison of emphysema and lung volume. Lung volumes were compared using the concordance correlation coefficient.

Results: The median low-attenuation areas (LAA) using filtered back projection (FBP) in standard dose was 4.4% and decreased to 2.6%, 2.1% and 1.8% using ADMIRE 3, 4, and 5, respectively. The median values of LAA in ultralow dose CT were 5.7%, 4.1% and 2.4% for ADMIRE 3, 4, and 5, respectively. There was no statistically significant difference between LAA in standard dose CT using FBP and ultralow dose using ADMIRE 4 ($p = 0.358$) as well as in standard dose CT using ADMIRE 3 and ultralow dose using ADMIRE 5 ($p = 0.966$). In comparison with standard dose FBP the concordance correlation coefficients of lung volumetry were 1.000, 0.999, and 0.999 for ADMIRE 3, 4, and 5 in standard dose, and 0.972 for ADMIRE 3, 4 and 5 in ultralow dose CT.

Conclusions: Ultralow dose CT at chest X-ray equivalent dose levels allows for lung volumetry as well as detection and quantification of emphysema. However, longitudinal emphysema analyses should be performed with the same scan protocol and reconstruction algorithms for reproducibility.

1. Introduction

Computed tomography (CT) of the lung has evolved to be the most widely used diagnostic tool for detailed imaging of the lung parenchyma [1–4]. Chest CT allows for a reliable detection of pulmonary emphysema and further enables to assess the pattern, severity and distribution of disease [5]. In addition the severity of emphysema can be quantified with software-based CT densitometry [6–8] by computing the low-attenuation areas (LAA) of the lung parenchyma, which represent the histological correlate of the dis-

Abbreviations: ADMIRE, advanced modeled iterative reconstruction; CT, computed tomography; LAA, low-attenuation areas; ROC, receiver-operator characteristic; IR, iterative reconstruction.

* Corresponding author at: Department of Nuclear Medicine, University Hospital Zurich, Ramistrasse, Zurich, Switzerland.
E-mail address: michael.messerli@usz.ch (M. Messerli).

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ease (i.e. permanent airspace destruction) [9]. Various studies have shown a high correlation of LAA values by CT with pathological findings and pulmonary functional test results [10,11].

Meanwhile, the ongoing debate about potential harmful effects of CT-related radiation exposure has urged the radiological community to optimize examination protocols. The strategies for reducing radiation dose include lowering of the tube current and tube voltage, automatic exposure control and iterative reconstruction (IR) [12].

A recently introduced CT device includes a tin-filter for single-energy imaging, which allows for spectral shaping of the X-ray beam. In combination with advances in IR – i.e. advanced modeled iterative reconstruction (ADMIRE) – both measures contribute to a drastic dose reduction [13,14]. A recent study investigated the value of chest CT with radiation dose levels as low as 0.13 mSv for detecting solid pulmonary nodules with the help of computer-aided detection software [15].

The value of these new techniques for emphysema quantification and lung volumetry was not investigated so far. Further, only a few studies have investigated the influence of IR techniques on the CT evaluation of pulmonary emphysema and lung volumetry [16,17], but none have evaluated latest generation IR in a clinical setting.

The purpose of this study was therefore to determine whether ultralow dose chest CT with tin filtration can be used for emphysema quantification and lung volumetry and to assess differences in emphysema measurements and lung volume between standard dose and ultralow dose CT scans using ADMIRE.

2. Materials and methods

2.1. Subjects

This study was performed in subjects enrolled in an ongoing prospective single-center trial (clinicaltrials.gov identifier NCT02468609). The inclusion criteria of the trial have previously been described [18]. Briefly, patients who were referred for a standard of care chest CT to our department (hereafter called standard dose CT), (a) aged $\geq$ 18 years, (b) excluded pregnancy, (c) and provided informed consent were enrolled and underwent an ultralow radiation dose CT that was conducted in addition to the clinically indicated standard dose CT in the same session. The local ethics committee approved the study. All patients gave written informed consent prior to inclusion. The study was conducted in compliance with the ICH-GCP-rules and the declaration of Helsinki.

In the present study we included a total of 90 consecutive patients with (a) absence of obesity defined as a BMI > 35 kg/m^2, (b) absence of diffuse pulmonary and/or pleural disease hampering the software-based segmentation (e.g. lobar atelectasis). We excluded a total of 6 patients because of technical failure of the automatic lung segmentation software. The final study population thus comprised 84 patients (Table 1).

2.2. CT data acquisition and image reconstruction

All examinations were performed using a third-generation dual-source CT (Somatom Force, Siemens Healthcare, Forchheim, Germany). A slice acquisition of 192 × 0.6 mm by means of a *z*-flying focal spot and a collimation of 96 × 0.6 mm were used. The rotation time of the gantry was 0.5 s at a pitch of 1.2, and all scans were acquired in full inspiratory breath hold. The study patients were scanned with our clinical standard chest CT protocol, followed by the ultralow dose acquisition with the same *z*-axis coverage. Standard dose scans were obtained at reference settings of 110 kV and 50 quality reference mAs using automated attenuation-based tube current modulation (CAREDose4D) and automated attenuation-based tube potential selection (CAREkV; setting 7). The ultralow dose CT scans were performed at a fixed tube potential of 100 kV and a fixed tube current–time product of 70 mAs with tin filtration of the X-ray spectrum, resulting in a $CTDI_{vol}$ of 0.24 mGy.

For image reconstruction third generation model-based IR (i.e. ADMIRE) was used, which includes a total of 5 incremental strength levels, where level 1 has the lowest and level 5 has the highest degree of noise reduction [19]. Standard dose CT images were reconstructed with filtered back projection (FBP) and with ADMIRE at strength levels of 3, 4 and 5. Ultralow dose CT images were reconstructed with ADMIRE at strength levels of 3, 4, and 5. A slice thickness of 1 mm and an increment of 0.7 mm using a smooth tissue convolution kernel (Br40) was used as generally recommended for lung volumetry and software-based emphysema assessment [20]. The reconstructed field-of-view was 400 × 400 mm.

Table 1
Demographics of study patients (n = 84).

Female/male	32 (38%)/52 (62%)
Age, years	57 ± 15 (18–81)
Weight, kg	72 ± 17 (40–132)
Height, m	1.71 ± 0.1 (1.54–1.92)
BMI, kg/m^2	24.3 ± 4.3 (16.2–35.0)
Clinical indications for CT	
Known or suspected tumor	43 (51%)
Suspected pulmonary infection	3 (4%)
Work up or follow up of pulmonary nodule	8 (10%)
Work up or follow up of pulmonary disease	22 (26%)
Abnormal chest X-ray findings	2 (2%)
Vascular (e.g. suspected pulmonary embolism)	5 (6%)
Thoracic skeleton assessment	1 (1%)
Conducted CT study	
Contrast enhanced CT	72 (86%)
Non-enhanced CT	12 (14%)

BMI, body mass index; CT, computed tomography; presented as n (%) and mean ± SD (range).

Table 2
Radiation dose parameters of study protocols.

	Standard dose CT	Ultralow dose CT	p-value[b]
$CTDI_{Vol}$, mGy	3.0 ± 1.1 (1.1–6.7)	0.24[a]	<0.001
Scan length, cm	35.5 ± 2.7 (29.9–43.1)	35.5 ± 2.7 (29.9–43.1)	1.000
DLP, mGy cm	120.1 ± 42.0 (45.9–252.8)	9.7 ± 0.7 (8.3–11.6)	<0.001
ED, mSv	1.7 ± 0.6 (0.6–3.5)	0.14 ± 0.01 (0.12–0.16)	<0.001

CT, computed tomography; $CTDI_{vol}$, volume CT dose index; DLP, dose length product; ED, effective dose, presented as n (%) and mean ± SD (range).
[a] Fixed tube potential and fixed tube current-time product.
[b] Wilcoxon-test for paired non-parametric data.

2.3. Radiation dose

For estimation of the effective dose the automatically logged dose-length-product was multiplied with a conversion coefficient k of 0.014 mSv/mGycm [21]. Further parameters of the CT protocols are presented in Table 2.

2.4. CT data analysis

2.4.1. Image noise

Image noise of standard and ultralow dose CT including all datasets (n = 588) was measured by a blinded reader in random order by placing a region of interest (ROI) in the aortic root and in the trachea above the level of the carina, representing the central