Low-dose MDCT of the lung: image quality in adults with cystic fibrosis versus other non-malignant lung disease

Poster No.: C-0325
Congress: ECR 2013
Type: Scientific Exhibit
Keywords: Lung, Respiratory system, Thorax, CT, CT-High Resolution, Comparative studies, Diagnostic procedure, Perception image, Pathology, Tissue characterisation, Artifacts
DOI: 10.1594/ecr2013/C-0325

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Purpose

Computed tomography (CT) represents the most accurate imaging modality to detect, diagnose, and follow up on lung disease. While currently being involved in about 10% of all radiological examinations, CT contributes about 50% to the collective diagnostic medical radiation dose [1][2]. Chest CT has been implied as a major contributor [3]. European Council Directive 97/43 demands that radiation exposure should be limited such as to confirm the suspected diagnosis [4], according to the "ALARA"- (as-low-as-reasonably-achievable-) principle.

Different approaches to the ALARA principle may be taken in chest CT. Decreasing the tube current-time product (TCTP) appears to be physically plausible, because it does not change X-ray quality at chest CT [5]. TCTP correlates linearly with radiation exposure and simply exponentially with image-degrading noise. TCTP may be adjusted to patient weight [6][7][8][9]. Vendors of clinical multi-detector-row CT (MDCT) scanners offer different means of automatic adaptation of TCTP to anatomic contours and X-ray transmission of the body [10]. However, there are technical limits in MDCT scanners to TCTP reduction. Chest CT at the limit of TCTP has been successfully applied in the computer-assisted diagnosis of lung nodules [11]. Less extreme TCTPs have been reported for chest CT screening of early lung cancer [12][13][14].

Retrospective, intra-individual comparison of chest MDCT at 120 KVp, with TCTPs of 100 mAs/slice (standard-dose MDCT or SDCT) and 10 mAs/slice (low-dose MDCT or LDCT), respectively, demonstrates that delineation of smallest lung structures differs only in the lung periphery, with about 70% of LDCT and 88% of SDCT scans yielding good or excellent results [15].

Our institution has applied an LDCT protocol at 120 KVp and the lowest technically achievable TCTP continuously since February, 2002, for adult patients with cystic fibrosis (CF), who require recurrent chest imaging [16][17]. Following clinical demand, LDCT was extended to the follow-up of other non-malignant lung disease in adult patients.

Five independent readers retrospectively evaluated the study hypotheses that there were no significant differences in the quality of delineation of smallest (<1.5 mm diameter) vascular and bronchial structures in the central and subpleural lung, respectively, between CF patients and patients with other non-malignant lung disease, and that quality of delineation was not influenced by potential confounders, including patient gender, age, body height, body weight, body mass index (BMI) [18], and sagittal and transversal body diameters at the level of the tracheal carina.
Methods and Materials

LDCTs of the chest of 105 consecutive adult patients (female, n=55, male, n=50), with an age of at least 18 years, height and weight records no older than 12 weeks, and clinical indications including CF (37 patients), pneumonia (23 patients), chronic obstructive pulmonary disease (COPD), bronchial asthma or chronic bronchitis (21 patients), fibrotic or granulomatous lung disease (12 patients), pneumothorax (4 patients), hypersensitivity pneumonitis (3 patients), follow-up on pulmonary nodules (3 patients), and follow-up on pulmonary venous congestion (2 patients) were retrospectively analysed.

The institutional review board ruled that this retrospective analysis was ethically unobjectionable. Data included in this study were analysed and presented in accordance with the World Medical Association (WMA) Declaration of Helsinki Ethical Principles for Medical Research Involving Human Subjects, as last amended by the 59th WMA General Assembly, Seoul, October 2008.

LDCT of the chest at 120 KVp, with patients positioned supine, head first, and arms elevated over the head, was performed on a clinical 4-row-MDCT scanner (Philips Mx8000, Philips Medical Systems, Hamburg, Germany), with the lowest technically achievable tube current of 35 mA, rotation time 0.5 s, collimation, 4x1 mm, pitch, 1.75, effective TCTP per slice, 10 mAs, effective slice thickness, 1.3 mm, reconstruction slice thickness, 1.3 mm and 3 mm, filtered back projection (FBP), reconstruction algorithm "C" or "D", weighted CT dose index (CTDIw), 1.0 mGy, resulting in an average effective dose of about 0.50 mSv for an adult female patient, as previously reported [15] [19].

LDCT images were retrieved from a picture archiving and communication system (PACS, Agfa Impax Version 4104.09.2004, Agfa, Munich, Germany) and displayed for evaluation on 1k-PACS monitors with one image per screen, at window width and window level settings of W 1,600 HU and L -600 HU (lung window), respectively. One investigator not involved in reading LDCTs (CDL) recorded respective sagittal and transverse body diameters at the level of the tracheal carina in axial LDCT images, randomized the reading order of LDCT scans for each reader, instructed readers how to use a previously validated scoring system [15], and recorded reading results. Evaluation was restricted to axial LDCT images at three distinct anatomical lung levels, i.e., at the top of the tracheal carina, 5 cm above, and 5 cm below.

Scoring was based on the summary impression of the delineation of smallest (<1.5 mm) bronchi and blood vessels within ventilated lung parenchyma, distinguishing
- suboptimal delineation, with smallest (<1.5 mm) bronchi and blood vessels either not recognized or recognized but not delineated from neighbouring structures and air space, and

- sufficient delineation, with smallest (<1.5 mm) bronchi and blood vessels either recognized and partially delineated from neighbouring structures and air space, or delineation partially blurred, or recognized and fully delineated from neighbouring structures and air space.

Distinction was made for different lung regions, namely the right and left central lung region, i.e., the lung from the hilus to the subpleural region, and the right and left peripheral (subpleural) lung region, i.e., the lung parenchyma within 2 cm of the visceral pleura.

All data were entered into and stored in Microsoft Excel 2003 worksheets (Microsoft Corporation). Statistical differences between patients with CF and patients with other non-malignant lung disease in the respective proportions of patients with sufficient and suboptimal image quality in the central and peripheral lung regions were then calculated for each of the five independent readers, applying Fisher's Exact Test with two tails or the Chi-Square-Test with Yates’s continuity correction on a significance level of p<0.05 [20].

Study results were then re-organized for the five independent readers to distinguish between LDCT scans with sufficient and suboptimal image quality in the central and peripheral lung regions, respectively. Patients for whom at least three of the five readers agreed on suboptimal image quality at least in the peripheral lung regions were considered to be patients with suboptimal overall LDCT result and distinguished from the other patients, whose LDCT results was considered to have been sufficient overall. As potential confounders of LDCT image quality, patient gender, height, weight, body mass index (BMI), sagittal and transverse body diameters, and age were compared between patients with sufficient and suboptimal overall image quality, respectively, applying Student's T-Test with two tails, under the assumption of different variance, on a significance level of p<0.05 [20].

Body mass index (BMI) was calculated according to World Health Organization (WHO) criteria as

\[ \text{BMI} = \frac{\text{patient weight [kg]}}{\text{patient height [m]}^2} \] [18].

Cut-off levels for each potential confounder that demonstrated a significant statistical difference between patients with sufficient and suboptimal LDCT results, respectively, were retrospectively determined. The respective potential decision accuracy of each
significant confounder for the inclusion of patients with sufficient and exclusion of patients with suboptimal LDCT results was estimated, with a cut-off-value of 80% to be considered as clinically useful.
Results

The five independent readers found delineation by LDCT of smallest bronchial and vascular structures in the central lung to be sufficient in 97-100% (median, 100%) of CF patients and in 91-94% (median, 93%) of patients with other non-malignant lung disease, respectively, without any statistically significant differences. Delineation by LDCT of smallest bronchial and vascular structures in the subpleural lung regions varied between different readers, both in CF patients (median, 92%, range, 49-97%) and patients with other non-malignant lung disease (median, 72%, range, 51-87%), with significantly better results in CF patients for three of the five independent readers (Figs. 1-6). Three or more of the five independent readers agreed on suboptimal delineation by LDCT of smallest bronchial and vascular structures in the subpleural lung regions in 2 of 37 CF patients (5%) and 16 of 68 other patients (24%, chi-square 4.3388, 0.025<p<0.050).

Among the potential confounders of delineation by LDCT of smallest bronchial and vascular structures in the subpleural lung regions, patient gender (sufficient, 46 female, 41 male, suboptimal, 9 female, 9 male, chi-square 0.0014, p>0.5) and body height (p=0.7471) did not differ between sufficient and suboptimal LDCT examinations. Patient body weight (p=0.7471), BMI (p=0.7471), sagittal (p=0.7471) and transverse (p=0.7471) body diameters at the level of the tracheal carina, and age (p=0.7471) each showed statistically significant differences (Fig. 7). When cut-off values for the inclusion into or exclusion from LDCT imaging of the lung were retrospectively determined for significant confounders, only body weight (up to 80.0 kg), BMI (up to 25.0 kg/m$^2$), and sagittal body diameter (up to 26.5 cm) demonstrated respective decision accuracies exceeding 80%.
Fig. 1: Figure 1. 31-year-old female patient with cystic fibrosis (CF). Body height was 158 cm, weight, 57.0 kg, body mass index, BMI, 22.8 kg/m2, sagittal chest diameter, 22.3 cm, transverse chest diameter, 29.9 cm. Delineation of smallest bronchial and vascular structures was found to be sufficient in the central lung by 5 of 5, and in the peripheral lung by 4 of 5 independent readers, respectively. Low-dose MDCT image were obtained at the level of the tracheal carina.

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**Fig. 2:** Figure 2. 31-year-old female patient with cystic fibrosis (CF). Body height was 158 cm, weight, 57.0 kg, body mass index, BMI, 22.8 kg/m², sagittal chest diameter, 22.3 cm, transverse chest diameter, 29.9 cm. Delineation of smallest bronchial and vascular structures was found to be sufficient in the central lung by 5 of 5, and in the peripheral lung by 4 of 5 independent readers, respectively. Low-dose MDCT image obtained 5 cm below the level of the tracheal carina.

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Fig. 3: Figure 3. 31-year-old female patient with cystic fibrosis (CF). Body height was 158 cm, weight, 57.0 kg, body mass index, BMI, 22.8 kg/m2, sagittal chest diameter, 22.3 cm, transverse chest diameter, 29.9 cm. Delineation of smallest bronchial and vascular structures was found to be sufficient in the central lung by 5 of 5, and in the peripheral lung by 4 of 5 independent readers, respectively. Low-dose MDCT images were obtained 5 cm above the level of the tracheal carina.

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**Fig. 4:** Figure 4. 61-year-old female patient with chronic obstructive pulmonary disease (COPD). Body height was 164 cm, weight, 83.0 kg, body mass index, BMI, 30.9 kg/m², sagittal chest diameter, 28.2 cm, transverse chest diameter, 34.2 cm. Delineation of smallest bronchial and vascular structures was found to be sufficient in the central lung by 3 of 5, and in the peripheral lung by 1 of 5 independent readers, respectively. Low-dose MDCT image obtained at the level of the tracheal carina.

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Fig. 5: Figure 5. 61-year-old female patient with chronic obstructive pulmonary disease (COPD). Body height was 164 cm, weight, 83.0 kg, body mass index, BMI, 30.9 kg/m², sagittal chest diameter, 28.2 cm, transverse chest diameter, 34.2 cm. Delineation of smallest bronchial and vascular structures was found to be sufficient in the central lung by 3 of 5, and in the peripheral lung by 1 of 5 independent readers, respectively. Low-dose MDCT image obtained 5 cm below the level of the tracheal carina.

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Fig. 6: Figure 6. 61-year-old female patient with chronic obstructive pulmonary disease (COPD). Body height was 164 cm, weight, 83.0 kg, body mass index, BMI, 30.9 kg/m², sagittal chest diameter, 28.2 cm, transverse chest diameter, 34.2 cm. Delineation of smallest bronchial and vascular structures was found to be sufficient in the central lung by 3 of 5, and in the peripheral lung by 1 of 5 independent readers, respectively. Low-dose MDCT image obtained 5 cm above the level of the tracheal carina.
Fig. 7: Figure 7. Potential confounders of delineation of smallest (}

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Conclusion

This retrospective analysis of the delineation by LDCT of smallest bronchial and vascular structures in the central and subpleural lung regions, respectively, compared adult patients with CF and adult patients with other non-malignant lung disease. In contrast to previous findings in patients with different lung diseases [15], the majority of readers in this study found delineation sufficient in the subpleural lung regions in CF patients. There was a statistically significant advantage for CF patients both among individual readers and when individual results were cumulated such that agreement of at least three readers was necessary to call delineation of smallest subpleural structures either sufficient or suboptimal. From a clinical point of view, LDCT at 120 KVp and the lowest technically achievable effective TCTP, thus appears to be technically suitable for CF patients.

When comparing all patients with agreement of at least three readers on sufficient subpleural image quality, distinguishing confounders included body weight, BMI, and sagittal chest diameter at the level of the tracheal carina, at cut-off values of 80 kg, 25 kg/m², i.e., normal BMI by WHO criteria [18], and 26.5 cm, respectively. Several previous studies have applied body weight as a discriminator in the assignment of patients to a dose-reduced chest CT examination [6][7][8][9]. From a clinical point of view, body weight estimates should be easy to obtain, while BMI estimates require knowledge of both body height and body weight, and the application of a mathematical formula or a table of respective values [18]. Performing measurements of sagittal chest diameter at the level of the tracheal carina would require specific skills among staff operating the MDCT scanner.

As a limitation, our retrospective analysis was based on 4-row MDCT images obtained with one particular CT scanner, while MDCT scanners with 16-64 detector rows have been in clinical use for several years [10]. However, while individual MDCT imaging parameter settings may vary between different scanners and different vendors, the common denominators would be a tube charge of 120 KVp, which is typical for MDCT chest protocols [10], and the lowest TCTP setting that would still yield chest images at 120 KVp. While that TCTP may vary between scanners, both the resulting weighted CT dose index (CTDIw) of 1.0 mGy and the average effective dose estimate of about 0.50 mSv for an adult female patient of average height and weight [15] [19], would be transferable to other MDCT scanners.

In conclusion, MDCT of the chest at 120 KVp and the lowest TCTP that would still yield chest images demonstrated sufficient delineation of smallest bronchial and vascular structures both in central and subpleural lung regions in approximately 95% of CF patients. Patients with other non-malignant lung disease may be assigned to such dose-reduced chest MDCT protocols with expectations of
sufficient image quality in the entire lung when their body weight does not exceed 80 kg, or, alternatively, when their body mass index is normal (25 kg/m$^2$ or lower). It remains to be elucidated if iterative image reconstruction algorithms allow for further dose reduction or improved image quality.
References


