Chapter 2

Diagnostic information of CT at the radiation dose level of a chest X-ray: A feasibility study

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Preliminary Report

ABSTRACT

PURPOSE

To investigate whether ultralow-dose computed tomography (LDCT) can provide more reliable information than plain chest X-ray (CXR) in two directions.

MATERIAL AND METHODS

We enrolled 40 consecutive patients from the outpatient department of pulmonology with a wide range of chest abnormalities, referred for chest CT. Four patients had to be excluded from further analysis because of study incompletion. The clinically indicated CT-scans (RCT) were performed on a multirow-detector scanner (16x0.75mm collimation 120kVp;130mAs, 4.6mSv) followed by a low-dose CT-scan (LDCT) performed with identical parameters except for radiation dose (90kVp;20mAs, 0.3mSv). Posterior-anterior and lateral CXR (0.1mSv) were performed on the same day. Chest abnormalities were scored by three observers using a scale from 1 (definitely absent) to 5 (definitely present) for lesions located in the lungs (8 items), mediastinum (3 items) and pleura, chest wall and bones (=3 items). RCT was used as reference standard with only scores of 1 and 5. Both, agreement with RCT and reader confidence were used as surrogate for diagnostic performance of CXR and LDCT. Significance of difference was evaluated by McNemar χ^2-testing.

RESULTS

LDCT and RCT showed a higher agreement than CXR and RCT for pleura, chest wall & bones and mediastinum (all $p<0.001$). This was true for analysis of pooled reader data as well as for the three observers separately. Two of the three readers showed a higher confidence with LDCT (both $p<0.001$), while one observer showed a superior confidence with CXR ($p<0.001$).

CONCLUSION

Using agreement of diagnostic interpretation as surrogate of diagnostic performance we found a superior performance of LDCT as compared to CXR, both obtained at a comparable dose levels of less than 1mSv. Further evaluations are needed to define potential and limitations of LDCT with respect to specific diagnostic indications.

INTRODUCTION

Chest computer tomography (CT) has proven to be superior to plain chest radiographs (CXR) in detecting a broad range of abnormalities [1;2]. In contrast to plain radiographs, CT-scan is not hampered by the superimposition of anatomic structures and has better contrast and resolution. Advantages of CT are earlier detection (e.g., of pulmonary embolism, nodules, cancer screening), correct classification (e.g., of interstitial lung diseases, asbestosis, sarcoidosis), better staging (e.g., of bronchogenic cancer) and a better differential diagnosis (e.g., by high resolution CT) of abnormalities. The introductions of spiral and multirow-detector scanners have further improved the sensitivity of CT. At the moment, a substantial number of patients receive a consecutive CT-scan after CXR, when the chest X-ray has not been decisive for diagnosis.

The major disadvantage of CT is its radiation burden and the associated hypothetical cancer risk to the patient [3;4]. With present standard techniques, between 4 and 8 mSv effective dose is delivered (UNSCEAR rapport 2001), which leads to a calculated risk of dying from radiation-induced cancer of 2-4 in 10.000 (30-year old) individuals. The risk, however, is strongly age-dependent and decreases sharply for elderly individuals (up to a factor of 5), while it increases for children (up to a factor of 5). For this reason, the development of low-dose scanning protocols is of importance, especially as CT is now increasingly being used for screening purposes and imaging of non-malignant disease such as pulmonary embolism [5-8] also in young patients.

New developments in the field of multislice scanning have made it possible to substantially reduce radiation exposure to as little as 0.1-0.2 mSv (ultralow-dose scanning) [9]. This exposure is in the range of a plain posterior-anterior and lateral chest radiographic exam. The associated radiation burden is then in the range of one to two months of natural background radiation. Ultralow-dose CT-scanning can be an option in patients when diagnostic information of a plain chest X-ray is not sufficient, but the additional information potentially does not exceed the risk of increased radiation dose of a standard dose CT-scan.

Aim of this feasibility study was to determine if ultra-low dose CT has the potential to provide more information as a CXR at a radiation dose that remains in the range of a plain posterior-anterior and lateral chest radiographic exam. For that purpose we used the agreement rate with the reference CT, performed with standard radiation dose, as surrogate for diagnostic performance of CXR and LDCT.

MATERIAL AND METHODS

PATIENTS

The study was approved by our institutional review board and written informed consent was obtained from all patients. Between September 2003 and May 2004, we enrolled 40 adult patients (26 men, 14 women, 20-81 years old, mean 57 yrs) from the outpatient department of pulmonology, who were referred for a chest CT because of the following indications: aspergilloma (n=1), malignancy (n=6), COPD/ emphysema (n=5), bronchiectasis (n=4), hemoptysis (n=3), pneumonia (n=2), interstitial disease (n=6), dyspnoea (n=6), coughing (n=1), pneumothorax (n=1), aspiration (n=1), chylothorax (n=1), depression (n=1) and sarcoidosis (n=2).

IMAGE ACQUISITION

First we performed the standard-dose chest CT-scan for clinical purposes immediately followed by an ultra-low dose CT-scan. This way, both scans were performed either with or without contrast-enhancement. No patient received contrast alone for the ultra-low dose CT-scan. All scans were acquired on a 16-slice CT scanner (Mx8000 IDT, Philips Medical Systems, Cleveland, OH) using a spiral mode with 16x0.75mm collimation and 15mm table feed per rotation (pitch = 1.3). The entire chest was scanned in about 10 seconds using a caudo-cranial scan direction. Scans were performed in full inspiration after appropriate instruction of the patients.

Axial images were reconstructed at 1.0mm thickness and 0.7mm increment, using a moderately soft kernel (B, Philips Medical Systems), the smallest field of view (FOV) that included the outer rib margins at the widest dimension of the thorax and a 512x512 matrix. For the additional ultralow-dose examinations (LDCT) we applied the lowest exposure settings possible at our CT scanner: 20mAs and 90kVp (volume CT dose index, CTDIvol = 0.6 mGy) for all patients, independent of patient size. The exposure settings for our clinical chest CT examinations are 150mAs at 120kVp (CTDIvol = 10.5mGy).

All patients underwent a plain chest X-ray on the same day as the CT was performed. The chest X-ray was obtained using state-of-the art digital storage phosphor technology (Optimus, Philips Medical Systems).

IMAGE EVALUATION

All images were blinded before the reading sessions and read without clinical information. The chest X-rays were read on a digital workstation (Philips Medical Systems, Cleveland, USA) connected to the picture archiving computer system (PACS). Observers were asked to read the images as they are used to do in clinical practice, including the use of editing tools available on the workstation. The CTs were transferred to a stand-alone workstation (Philips Medical Systems, Cleveland, USA), which is also used in clinical routine in our hospital along with

the PACS-system. The window width and level and the viewing direction could be manipulated along to the preferences of the reader. The readers were also able to adapt on-line the section thickness and use multiplanar reformats in coronal and sagittal direction if wanted. These tools were equally available for both types of CT examinations.
Three observers with different levels of experience (two board certified radiologists with 20yrs and 3yrs of experience dedicated to chest imaging, respectively and a fourth year resident) evaluated all images for the presence or absence of an abnormality. Chest X-rays were the first examinations to be read, followed by the ultra-low dose CTs in a second session and the reference CTs in a final session. Between the reading sessions there was at least a one-week interval. The order of images varied for the different techniques and the three readers.
According to a predefined questionnaire, the readers assessed the presence or absence of pathology using a five point scale ranging from 1 (definitely absent) and 2 (probably absent) to 3 meaning equivocal and 4 and 5 meaning probably and definitely present, respectively.
Pathologic findings were classified according to their anatomic location as intraparenchymal findings, pleura & chest wall, and mediastinal lymph nodes. Readers were asked to assess the presence or absence of the following lung findings: emphysema, small lung nodules (<1 cm), large lung nodules (1–3 cm), lung masses (>3 cm), non-specific linear or reticular opacities (including plate like atelectasis), consolidation/ atelectasis (not plate like), diffuse interstitial disease and airway disease. For the pleura the readers had to assess the presence of an effusion, thickening, or pneumothorax; in the chest wall, they were asked to document bone lesions. In the mediastinum they scored the presence or absence of hilar lymphadenopathy and mediastinal lymphadenopathy (paratracheal, subcarinal, aortopulmonal). For each of the three anatomic areas (lung, mediastinum and pleura/chest wall) the readers had the option to specifically document findings not fitting the predefined pathology. The observers also had the opportunity to indicate if additional imaging was required.

Data Analysis and Statistical Analysis

All reading data were entered in a spreadsheet program (Excel; Microsoft, Redmond, Wash.). For each observer, we used the data obtained from the standard dose CTs as internal reference standard (RCT). We compared the data from the ultra-low dose scans and from the plain X-rays to that internal standard separately for each observer. The overall objective of the data analysis was to determine the agreement rates between the ultra-low dose CT-scans and the standard dose CT-scans and between the plain chest X-rays and the standard dose CT-scans, respectively.
Secondly, we pooled the data of the three observers for all structures to determine which lesion type or anatomic category was most responsible for adversely affecting the agreement.

Statistical analysis was based on 2x2 tables, the McNemar test for paired data yielding $\chi 2$ statistic with one degree of freedom, was used to assess significance of difference between the off-diagonal elements in the 2x2 tables. Statistical analyses were performed using SPSS version 13.0 (SPSS, Chicago, Ill.). P-values <0.05 were considered to indicate a significant difference.

To produce 2x2 tables reading data from the five-point scale had to be reduced to a dichotomous data set. For that purpose scores 1-3 were grouped as "absent" and scores 4&5 were grouped as "present". Within each table, agreement between the reference standard and the ultralow-dose scans was reflected by the row margins, while the agreement between the reference standard and the chest X-ray was reflected by the column margins. The total number of interpretations was split up in frequency of agreement or disagreement, resulting in four cells. The left upper cell (A) reflected disagreement for both techniques, while the right lower cell (D) represented agreement for both techniques with the reference standard. In both other cells (B and C), one technique agrees with the reference technique, while the other did not. Comparison of the "off-diagonal" cells (A and D) in agreement and disagreement enables assessment whether the agreement of the chest X-ray with the reference technique differs from the agreement of the ultra-low dose CTs with the reference technique.

Finally, we assessed the level of reader confidence per reader and technique. For this purpose, reading data had to be reduced again to a dichotomous system: scores of 2,3 and 4 were replaced by zero and scores 1 and 5 by one. The frequency of zero and one were again placed in a 2x2 table, where disagreement was replaced by "low confidence (=0)" and agreement by "high confidence (=1)".

RESULTS

Thirty-six patients completed all examinations, resulting in 108 examinations to be read. Although the image quality of the LDCT of one very heavy patient was extremely poor, all images were eligible for analysis. All examinations were read by three observers, thus there were 108 (36x3) reports per item. In total 864 (8x36x3) structures were analyzed for the lungs, 324 (3x36x3) structures were analyzed for the chest wall & pleura and 218 (2x36x3) structures were analyzed for the hilar & mediastinal lymph nodes.
Averaged over three observers, for 89% of the reference CTs (97 out of 108 reference CTs) at least one abnormal structure was reported. Table 1 shows the number of structures reported as abnormal on RCT for each observer separately and after pooling the data. The number of reported abnormal structures ranged from 110 for observer 1 to 135 for observer 3. A large mass was the least frequent finding, while non-specific linear or reticular opacities were the most frequent reported finding.

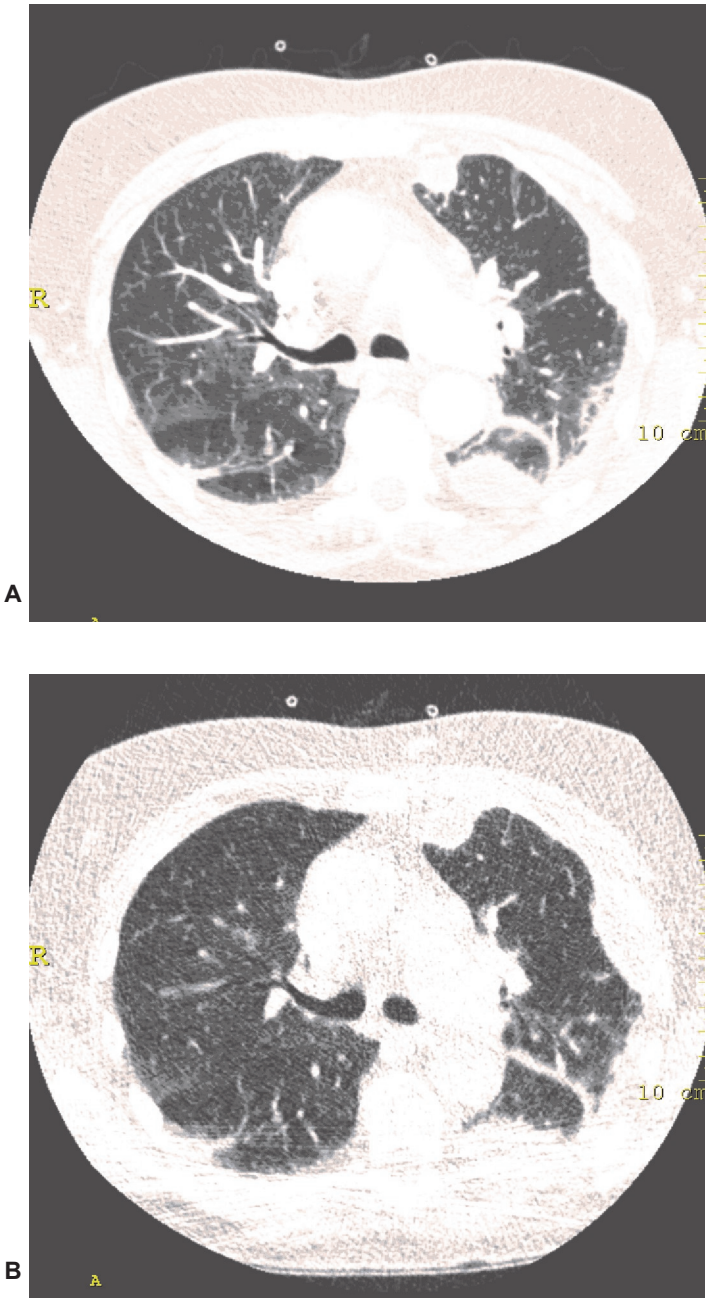

Figure 1

Standard dose (A) and ultra-low dose CT-scan (B) showing a similar image. Note that the mass dorsal in the left lung is obscured by artifacts on the ultra-low dose image, but can still be visualized.

Item	Observer 1	Observer 2	Observer 3	Total (%)
Lung				
Emphysema	7	7	7	21 (19)
Small lung opacities (< 1cm)	13	25	9	47 (44)
Large lung opacities (1-3 cm)	8	7	9	24 (22)
Lung mass (> 3cm)	2	0	1	3 (3)
Non-specific linear or reticular opacities	21	23	31	75 (69)
Consolidation/ Atelectasis (volume loss >1 segment)	6	11	15	32 (30)
Diffuse interstitial disease	5	2	5	12 (11)
Airway disease	22	12	11	45 (42)
Pleura & Chest wall				
Effusion/thickening	10*	19	24	53 (49)
Pneumothorax	2	2	1	5 (5)
Non-degenerative bone lesions	1	9	5	15 (14)
Mediastinum				
Hilar Lymphadenopathy	7	6	3	16 (15)
Mediastinal lymphadenopathy	6	11	13	30 (28)

*only pleural effusion

Table 1

Frequency of positive scores on standard dose CT-scan ("item present") for each observer separately and for all observers together.

For the pooled data of all three observers, we found a significantly higher agreement between LDCT and RCT for intraparenchymal abnormalities, pleural&chest wall abnormalities and the presence/absence of pathologically enlarged mediastinal or hilar lymph nodes (all $p<0.001$).

Analysis of the three observers separately also showed significantly more agreement between LDCT and RCT than between CXR and RCT ($p<0.001$ to $p=0.01$). Further sub analysis for each item revealed that the presence or absence of small pulmonary nodules (<1cm) ($p=0.03$), large pulmonary nodules (1-3 cm) ($p=0.02$) and airway diseases ($p=0.02$), were reported with higher agreement between LDCT and RCT than between CXR and RCT. No significant difference was demonstrated for the interobserver agreement between the CXR and the RCT ($p=0.17$ to $p=0.41$) or between LDCT and RCT ($p=0.09$ to $p=0.97$).

The level of confidence was significantly higher for LDCT compared to chest X-ray for observers 2 and 3 (both $p<0.001$), but significantly lower for observer 1 ($p<0.001$). For observer one, the number of items scored as probably absent (scored as 2) increased from n=45 (9.6%) to n=79 (16.9%), while for observers 2 and 3 the numbers decreased from 97 (20.9%) to 35 (7.5%) and from 103 (22.0%) to 59 (12.7%), respectively. The number of items scored as probably present (scored as 4) decreased for all three observers. For observer 1, the number of items scored as probably present decreased from 22 (4.7%) to 7 (1.5%), for observer 2 the number of items decreased from 23 (4.9%) to 6 (1.3%) and for observer 3 the number of items scored as probably present decreased from 37 (7.9%) to 7 (1.5%).

These results were supported by the number of indicated additional examinations. For the chest X-rays, the three observers reported that in 51/108 cases an additional examination was required, while for LDCTs the number of non-conclusive cases decreased to 35/108 ($p=0.01$).

DISCUSSION

Since CT is not hampered by over projection of several structures, CT can provide more information than plain X-rays, but at the cost of more radiation dose. The diagnostic information of a plain chest X-ray is often sufficient, but in many cases an additional CT is indicated. The main disadvantage of CT is its radiation burden and the associated hypothetical cancer risk to the patient [3], which is concerning more and more radiologists [10;11]. Multiple previous publications showed that in the thorax, where there is a high contrast between the lungs and most abnormalities in the lung such as nodular or reticular patterns, lung masses and air wall thickening, the radiation dose can be substantially reduced, still providing diagnostic information [12]. This technique has been realized in lung cancer screening trials [1;7;13-17], but in daily clinical practice low dose CT-scans are not routinely applied. However, in cases where the diagnostic information of a chest X-ray is likely to be insufficient and radiation dose, however, represents a not negligible risk, such as in young patients or in patients with benign disease or multiple follow ups, ultra-low dose CT may represent a diagnostically more effective alternative. Potential clinical indications include follow-up examinations of sarcoidosis, chronic interstitial lung diseases, bronchiectases and aspergilloma. Since we did not aim to assess the absolute diagnostic accuracy of one or the other technique and there was no absolute standard of truth in our study, we used the agreement with the most superior technique - namely the standard dose CT - as surrogate for diagnostic performance. The results of our study show the clear superior agreement between the LDCT and the RCT as compared to the CXR. This was true not only for lesions located in the lung parenchyma but also for lesions located in chest wall and mediastinum. Accordingly the level of confidence assessed by the relative frequency of definite instead of probable answers was higher with LDCT as with CXR for two of the three readers. One reader showed a higher confidence with CXR although her diagnostic agreement was higher with LDCT and RCT. This might be due to the fact that this reader felt irritated by the relatively high noise level in the LDCT images.

Multiple studies have been published, investigating the minimum dose required to provide enough diagnostic information and studies investigating the effect of dose reduction on image quality. Naidich et al already showed that lung parenchyma could be evaluated on CT-scans performed with 20mAs, without losing diagnostic quality [18], while Zwirewich et al demonstrated no significant difference in lung parenchymal structures between low-dose (40 mAs) and high-dose (400 mAs) thin section CT images, except for the presence of ground glass [12]. Ravenel et al reported that images obtained at 40mAs were all, except for one, deemed “adequate” for diagnostic purposes. While the results of our study are in agreement with these previous results in the respect that diagnostic information might be unchanged also in dose reduced scans, none of these previous studies reduced so drastically as in our study to the dose level of a CXR.

Only one study, published by Lee et al, has compared the performance of chest X-rays to low dose helical CT, delivering a comparable radiation dose [19]. Lee et al used a discontinuous high resolution protocol, performing three image, obtained at the aortic arch, at the tracheal carina, and 1 cm above the right hemidiaphragm. This approach of discontinuous data acquisition is still used today for follow-up of diffuse interstitial lung diseases, but has a limited value for other indications due to the fact that only a fraction of the lung parenchyma is scanned.

The main limitation of our study is the limited number of patients and diseases. The results may be interpreted in a way that the potential of LDCT could be shown, but more evaluation with respect to larger patient groups and specific disease entities is needed to conform our findings and more importantly to show the limitations of the ultra-low dose technique. Only then indications and patient groups can be defined that might take advantage of that technique according to the principle of ALARA.

The order of images was altered for reader and per technique all readers started with CXR, followed by LDCT and RCT at the last. We chose that order to start with the potentially least sensitive method and ending with the most sensitive method to avoid learning effects. Since the patient group, however, was relatively small, learning effects cannot be completely excluded, of so they are, however, unlikely to have affected the basic tendency of our results.

In conclusion, ultra-low dose CT performed at a radiation dose of a chest X-ray in two directions provides more diagnostic information than the plain chest X-ray as indicated by the higher agreement rate between the LDCT and the reference CT. Further analysis is needed to refine indications and patient groups that might take advantage of that technique.

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