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# Added Value of Ultra–low-dose Computed Tomography, Dose Equivalent to Chest X-Ray Radiography, for Diagnosing Chest Pathology

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**Purpose:** The purpose of this study was to assess the clinical value of ultra–low-dose computed tomography (ULDCT) compared with chest x-ray radiography (CXR) for diagnosing chest pathology.

**Materials and Methods:** A total of 200 patients referred for CXR by outpatient clinics or general practitioners were enrolled prospectively. They underwent CXR (posteroanterior and lateral) and ULDCT (120 kV, 3 mAs) on the same day. In-room time and effective dose were recorded for each examination. Studies were categorized whether they were diagnostic or not, relevant radiologic diagnostic findings were reported, and confidence for diagnosis was recorded by a Likert scale. Differences in diagnostic confidence and effect on management decision were compared.

**Results:** In-room time was <2 minutes for CXR and <3 minutes for ULDCT. Effective dose was 0.040 mSv for CXR and 0.071 mSv for ULDCT. CXR was considered diagnostic in 98% and ULDCT in 100%. The mean perceived confidence for diagnosis was 88 ± 12% with CXR and 98 ± 2% with ULDCT ($P < 0.0001$), whereas discrepant findings between CXR and ULDCT were found in 101 of 200 patients. As compared with CXR, ULDCT had added value for management decisions in 40 of 200 patients.

**Conclusions:** ULDCT provided added value to the radiologist by improved perceived confidence with a reduction in false-positive and false-negative CXR investigations that had management implications in 20% of patients. The effective dose of ULDCT will not be a limiting factor for introducing ULDCT of the chest on a broad scale in clinical practice.

**Key Words:** computed tomography, chest x-ray, comparative study, diagnosis, radiation exposure

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Digital chest x-ray radiography (CXR) is the imaging modality of first choice for detecting chest pathology. However, CXR has an important diagnostic limitation by being a 2-dimensional (2D) projection technique, wherein superposition of structures can cause misinterpretation that may lead to false-positive and false-negative results. Phantom studies,[1] as well as patient studies have shown that 3-dimensional (3D) volume computed tomography (CT) can increase confidence and correct diagnosis as compared with CXR investigations.[2,3] The major drawbacks for primary use of CT instead of CXR are the higher patient dose and costs. According to an European survey, the average effective dose for CXR (posteroanterior and lateral projection) is 0.10 mSv (range: 0.01 to 0.26 mSv). The effective dose for chest CT is about 50-fold higher with a typical value of 5.5 mSv (range: 2.0 to 20.4 mSv).[4] Several studies have shown that low-dose CT of the chest, below 1 mSv, is feasible for detecting and characterizing a variety of pulmonary and chest diseases.[5–8] It has also been shown by phantom studies[9,10] and patient studies that chest CT examinations performed by using ultra–low-dose CT (ULDCT) with doses equivalent to CXR examinations allows for detecting pulmonary nodules with comparable sensitivity as previous standard or low-dose CT techniques.[11–15] We hypothesize that ULDCT may not only improve detection of pulmonary nodules, but also the diagnosis for a wider range of pathologies. The purpose of our study was to assess the clinical performance and confidence for diagnosing chest pathology with ULDCT as compared with CXR examinations.

## MATERIALS AND METHODS

This prospective study was approved by the Institutional Review Board, and written consent was obtained from all patients. A total of 200 patients referred on clinical indication for CXR by either the outpatient clinics or general practitioners were enrolled in the study. The inclusion criteria were referral for CXR, at least 50 years of age, and being able to provide written informed consent. Exclusion criteria were body mass index (BMI) 30 kg/m$^2$ or more, not able to hold breath for at least 5 seconds, or pregnancy. No other exclusion criteria were used. For the included patients, age, sex, and BMI were recorded. Of the initial 205 patients who seemed eligible, 5 were excluded: 1 patient was positioned incorrectly during ULDCT acquisition, 1 patient had technically inadequate lateral CXR acquisition by motion, 2 patients had erroneously been included (1 with BMI of 34 kg/m$^2$, and 1 was 40 y of age), and 1 patient withdrew informed consent.

### Image Acquisition and Reconstruction

For each patient, CXR was performed first, followed by the additional ULDCT. Studies were performed on the same day to avoid possible pathology changes. The CXR was performed standing using a Triathlon DR vertical bucky unit (Delft DI, Odelft-Benelux, Delft, The Netherlands) with the following acquisition parameters:

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Posteroanterior 130 kV and lateral 133 kV, 320 mA, automatic exposure control, and filtration (2.5 mm Al, 0.1 mm Cu) were used. The field size was adapted individually for each patient. The ULDCT examination was performed using a volumetric 320-detector row CT scanner (Aquilion ONE Genesis edition, Toshiba Medical Systems, Otawara, Japan). Scanograms were not acquired during this study to save radiation dose. Instead, the start of the scan range was set manually at the gantry using the traditional laser beams. During the scan, real time reconstructions were observed and the scan was stopped using the abort scan button. The scan range was from the lung apex to the full diaphragm. The CT acquisition was performed with breath-hold during inspiration. Scan parameters were helical scan, 80×0.5 mm collimation, pitch 1.388, 120 kV, 10 mA, and 0.3 seconds rotation time. The associated $CTDI_{vol}$ is 0.1 mGy. No iodinated contrast material was used. Images were reconstructed in a 400 mm FOV with AIDR 3D Enhanced. AIDR 3D Enhanced is a hybrid (first generation) iterative reconstruction technique, which acts on the acquired projection data, applying models of the scanner and the statistical noise distribution on the basis of noise power spectrum, enabling reducing noise and streak artifacts while maintaining the spatial resolution. The number of iterations and blending ratio is optimized in the image domain. A low-frequency 3D filter is additionally applied to the projection data to control the noise grain size to avoid undesired oversmoothing in the reconstructed images.[16–18] Two series of images were reconstructed per patient. One series with 5 mm slices (2.5 mm spacing) and a soft tissue kernel (FC18) and another series with 1 mm slices (0.5 mm spacing) and a lung parenchyma kernel (FC08).

## In-room Time and Effective Dose

For both CXR and ULDCT investigations, the in-room time was measured in seconds. The in-room time was the time between entering and leaving the examination room. Moreover, the radiation dose was reported. For the CXR examination, the dose area product (DAP, mGy·cm$^2$) and, for ULDCT, the dose-length product (DLP, mGy·cm) per study were retrieved from the DICOM header. The effective dose (E) was calculated using a conversion factor of 0.22 mSv/Gy·cm$^2$ for posteroanterior and 0.14 mSv/Gy·cm$^2$ for lateral CXR.[19] For ULDCT, 0.014 mSv/mGy·cm for chest CT was used.[20]

## Clinical Findings

Clinical evaluation was performed on a PACS workstation in a darkened room[21] by either one of 2 board-certified radiologists (L.J.M.K. and A.d.R.), with >15 and 25 years of experience in clinical thoracic radiology, respectively. The radiologists assessed the images separately. The cases were divided randomly to the radiologist on the work floor and were clinically processed as and within the regular clinical work routine, with additional administration of scoring forms designed for the study. For each patient, both image quality and clinical findings were assessed by the same radiologist. The CXR examination requested was reported first and then the ULDCT. This reading order was selected so as to assess potential additional value of ULDCT as compared with CXR at the moment of clinical request, and because 3D volume ULDCT acquisition provides more spatial information than 2D projection CXR, whereas 3D knowledge could not be ignored anymore if 2D CXR was read after 3D volume ULDCT. Postprocessing tools were allowed. After having clinically reported the CXR, the radiologist determined dichotomously whether the study was classified as diagnostic or not diagnostic related to the initial clinical question. Relevant radiologic diagnostic findings were reported. The perceived confidence for diagnosis was reported on a Likert scale by percentage (0% to 100%). Perceived confidence expresses the experienced confidence of certainty about the diagnosis at the time of assessment. This was to compare the potential value of clinical use of ULDCT versus CXR, although we did not have an independent reference standard available. After CXR evaluation the same scoring criteria were applied for ULDCT.

## Statistical Analysis

Data are presented as mean and SD for continuous variables. Categorical variables are presented with frequencies and relevant percentages. To determine differences between CXR and ULDCT with regard to in-room time and effective dose, a paired 2-tailed student $t$ test with a SE of 5% and a 95% confidence interval was used. The percentages of diagnostic and nondiagnostic studies, and output with regard to the clinical question answered, were compared using the McNemar test for paired proportions. Differences in diagnostic confidence (expressed as a percentage) were tested with a paired 2-tailed student $t$ test. Statistical analysis was performed with SPSS for Windows (SPSS, version 24.0, Chicago, IL). $P$-values < 0.05 were considered to indicate statistically significant differences.

# RESULTS

The 200 patients included in this study comprised 104 men and 96 women. The mean age was 66.3 years (range: 50 to 90 y) for men and 65.2 years for women (range: 51 to 83 y). The mean BMI was 25.2 kg/m$^2$ for men (range: 20.1 to 29.9 kg/m$^2$) and 23.7 kg/m$^2$ for women (range: 17.1 to 29.7 kg/m$^2$).

## In-room Time and Effective Dose

For 185 patients, the in-room time was recorded for both ULDCT and CXR. These patients were included in the calculation of the average in-room time. The mean (±SD) in-room time was 100 ± 34 seconds for CXR and 178 ± 42 seconds for ULDCT, respectively ($P$ < 0.0001). The mean (±SD) effective dose was 0.040 ± 0.017 mSv (range: 0.011 to 0.10 mSv) for CXR and 0.071 ± 0.006 mSv (range: 0.056 to 0.081 mSv) for ULDCT ($P$ < 0.0001).

## Clinical Findings

Table 1 shows the clinical questions posed by the referring physician, categorized according to pathology type. The CXR was considered as diagnostic in 98% of the patients and ULDCT in 100% of the cases ($P$ = 0.045). Notwithstanding these high diagnostic percentages, discrepancy between CXR and ULDCT for diagnostic findings was found in half of the

**TABLE 1.** Clinical Question Categorized according to Pathology Type Together With the Number of Patients (and Percentage of the Total Number of Cases in the Study) Per Category

| Clinical Question Categories | No. Patients (N = 200) (n [%]) |
|---|---|
| Metastasis/tumor | 58 (29) |
| Pneumonia | 31 (15.5) |
| Follow-up lung carcinoma | 24 (12) |
| General Q pulmonary pathology/ abnormalities | 20 (10) |
| Congestive cardiac failure | 12 (6) |
| Follow-up lung disease | 12 (6) |
| Others | 43 (21.5) |

**TABLE 2.** Patient Management Implications: Cases With CXR False Negative With Regard to the Clinical Question and With Pathology Observed on ULDCT Examination (23 Patients)

| Pathology | No. Patients |
|---|---|
| Probably infectious pulmonary consolidations recommended for treatment | 9 |
| Nodules or possible metastasis with recommendation for follow-up | 6 |
| Signs of chronic obstructive pulmonary disease with clinical symptoms | 4 |
| Tumor decrease or residual tumor at lung cancer follow-up | 3 |
| Suspected symptomatic coronary sclerosis with aortic aneurysm | 1 |

patients (101/200). These were false-positive or false-negative findings related to the clinical question asked, and/or additional/incidental findings that could be relevant or not. These diagnostic differences were considered relevant in 68 of 101 patients. In 40 of these 68 patients, the differences between the CXR and ULDCT had management implications. This included contact with the referring physician for possible expected impact on diagnosis and/or therapy, and/or a change in management recommendation after ULDCT diagnosis, such as further analysis, follow-up imaging, referral, and/or treatment.

The impact on patient management, after ULDCT differed from CXR, had 3 main causes: the first category was false-negative results on CXR with regard to the clinical question, with pathology not observed on CXR but observed with ULDCT. Such new, unexpected findings were seen in 23 patients (Table 2). A patient example is shown in Figures 1 and 2. Please note that the confidence level for correct diagnosis was erroneously assigned as very good (95%) with CXR in this patient. Moreover, 4 of the patients in this group had an additional finding of an asymptomatic ascending aortic aneurysm found on ULDCT that was not observed on CXR.

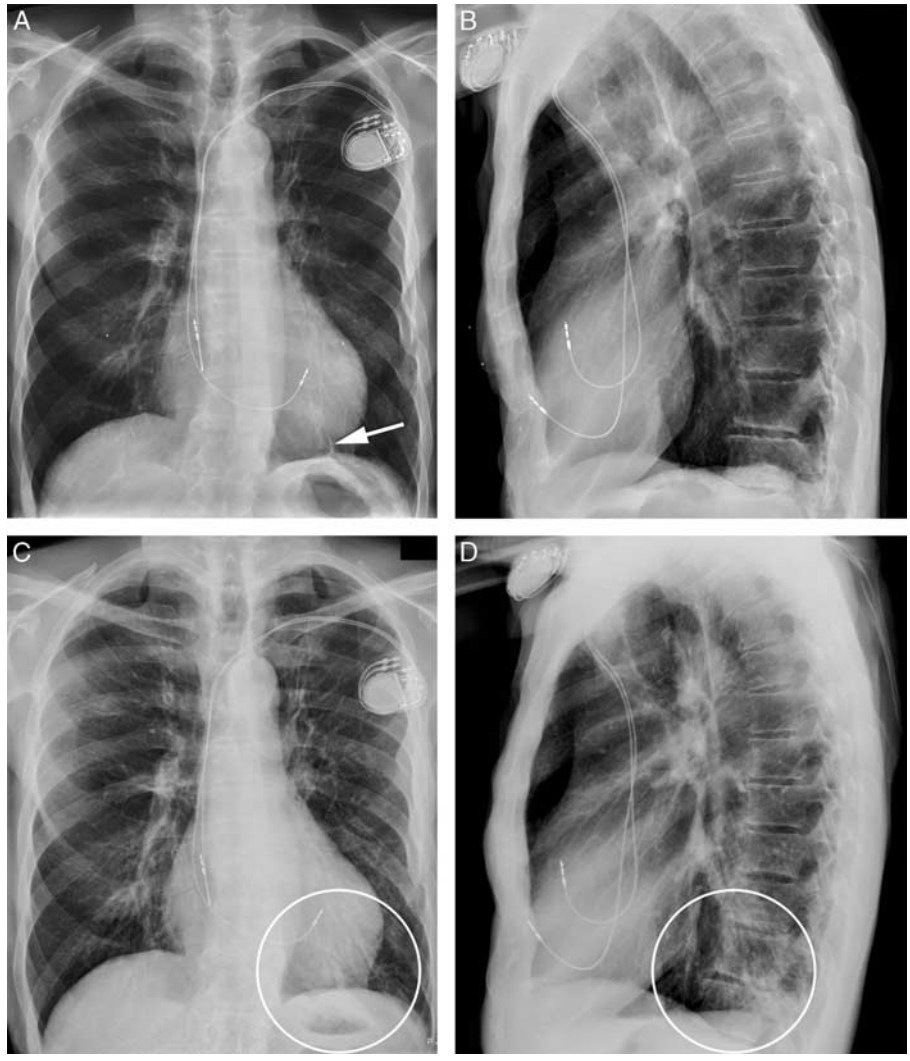


**FIGURE 1.** A 72-year-old male patient with metastasized melanoma and immunotherapy with recent pneumonia has recurrent fever of 40°C (104°F). The clinical question was "pneumonia?" CXR posteroanterior (A, C) and lateral projections (B, D). Small residual lesion in the left lower lobe (A, B, arrow in A) from previous pneumonia that has been resorbed; there are no signs of active pneumonia. CXR perceived confidence for diagnosis was 95%. Pneumonia 6 weeks before (C, D, encircled). In-room time was 110 seconds, effective dose 0.03 mSv.

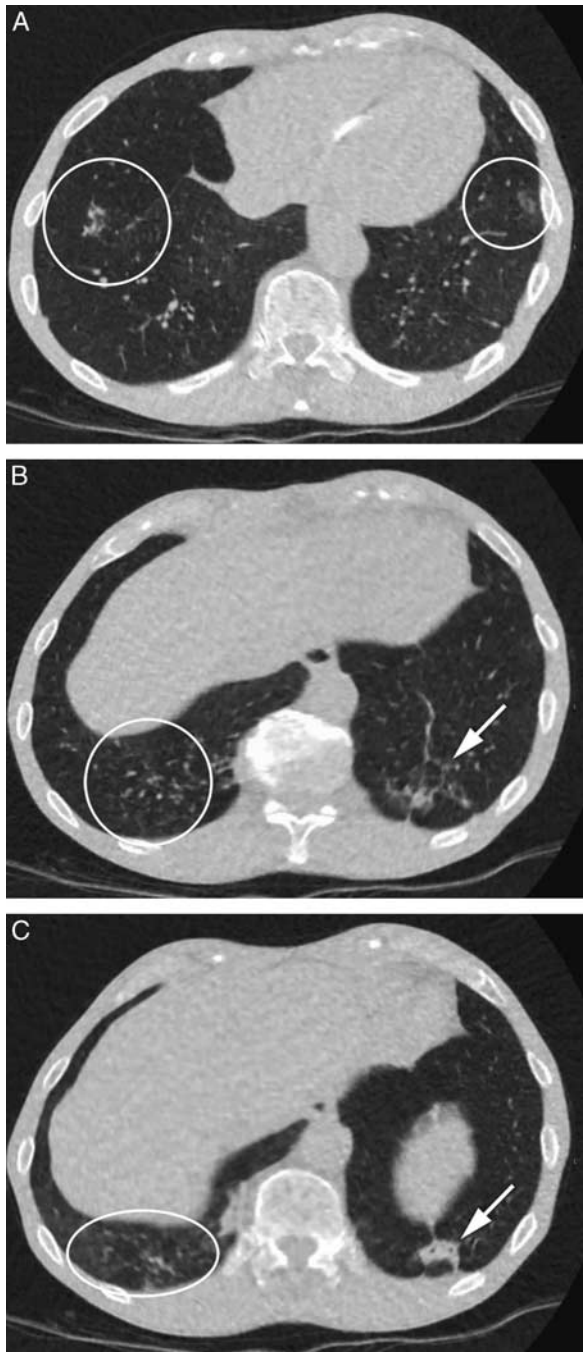


**FIGURE 2.** Same patient as in Figure 1. ULDCT from below, enlarged lymph nodes were excluded. Multiple foci with tree-in-bud aspect in the right lower lobe (A–C, encircled), not observed on CXR. A band-like density in the left lower lobe after previous pneumonia (B, C, arrow). ULDCT perceived confidence for diagnosis was 100%. Fever may be caused by immunotherapy itself, although the combination of illness, fever, and tree-in-bud pattern is likely active infection. The referring physician was contacted for expected therapeutic consequences. In-room time was 168 seconds, effective dose was 0.08 mSv.

The second category was false-positive or unsure results on CXR, affecting patient management because of the correct exclusion of abnormalities by ULDCT. This scenario occurred in 12 patients, in whom a chest abnormality was suspected on CXR, but could subsequently be excluded by ULDCT (Table 3). The management implication in these patients most often consisted of avoidance of a (normal dose) CT, which would otherwise have been advised after positive or unsure CXR, but where pathology was already excluded or confirmed on ULDCT (10 patients). In a patient with tuberculosis excluded by ULDCT, a 4-month medical tuberculosis treatment was avoided.

**TABLE 3.** Patient Management Implications: Cases With False Positive or Unsure Diagnosis in CXR and Exclusion by ULDCT (12 Patients)

| Pathology | No. Patients |
|---|---|
| Suspected malignancy or mass on CXR was excluded by ULDCT | 7 |
| Suspected bronchiectasis, emphysema, or TBC on CXR was excluded by ULDCT | 3 |
| Tumor progression on CXR was excluded by ULDCT | 1 |
| Unsure findings on CXR were confirmed on ULDCT | 1 |

The third category with effect on patient management comprised 5 patients because of incidental findings on ULDCT that were not observed on CXR but required follow-up or therapy. These included 2 patients with incidental nodules (9 and 10 mm) requiring follow-up, 1 patient with a 17 mm ground-glass opacity requiring follow-up, 1 patient with suspected recurrent breast cancer requiring further analysis (with carcinoma confirmed), and 1 patient with longstanding complaints, now presenting with severe hypertension and dyspnea, referred for CXR for suspected congestive cardiac failure. Cardiac failure was not observed on either CXR or ULDCT, but enlarged adrenals on ULDCT suggested possible Cushing syndrome. ULDCT prevented diagnostic delay for this clinically often difficult diagnosis, Cushing syndrome was confirmed soon afterwards, wherein complaints were explained by hypertensive crisis.

Furthermore, the residual group of 28 patients with relevant diagnostic difference (68 patients minus 40 patients with management implications), did have relevant improved diagnosis with ULDCT as compared with CXR, but the diagnostic difference was not expected to have management implications. These included 23 patients with upgrade of diagnosis by ULDCT because of improved and/or additional diagnosis, and 5 patients who had a diagnosis on CXR that was excluded by ULDCT (Table 4). One example is a patient who had 3 insufficiency fractures after radiotherapy for lung cancer that were not observed on CXR but were seen on ULDCT. This explained the pain that the patient had, but it was not related to the primary clinical question with regard to suspected pneumonia (Table 4, nr. 2/23 patients with additional diagnosis).

## Confidence for Diagnosis

The mean (±SD) perceived confidence for diagnosis was 88 ± 12% with CXR and 98 ± 2% with ULDCT ($P < 0.0001$). The distribution was wider with CXR with some investigations with relative low confidence as compared with ULDCT. Moreover, in all cases with diagnostic difference between CXR and ULDCT, the ULDCT was reported as having higher confidence than CXR. An example is shown in Figures 3 and 4, wherein ULDCT provides more information with better perceived confidence than CXR, regardless of (potential)

**TABLE 4.** Relevant Diagnostic Difference Between ULDCT and CXR but Without Management Implications

Cases where ULDCT showed additional diagnosis, as compared with CXR (23 patients)
1. CXR and ULDCT both showed resorption of pneumonia. ULDCT showed lung emphysema not observed on CXR
2. CXR and ULDCT similar in follow-up lung carcinoma. ULDCT showed 3 insufficiency fractures not observed on CXR
3. CXR could not answer the clinical question. ULDCT showed pleural effusion and postradiation abnormalities not observed on CXR
4. CXR showed consolidations and bronchial wall thickening, unsure. ULDCT showed nodules with cavitation, suspected for infection or metastasis
5. CXR showed interstitial lung disease and pleural effusion, and the differential diagnosis was rheumatic or parapneumonic disease. ULDCT showed normal airways, pleural effusion, and additional pericardial effusion, with added differential diagnosis of polymyositis
6. CXR and ULDCT both showed rest collection after empyema. ULDCT showed possible fistula with gas cavity, better follow-up of changes, and better differential between pleural effusion, atelectasis, or consolidation
7. CXR and ULDCT both excluded metastases. ULDCT showed enlarged lymph nodes not observed on CXR
8. CXR showed increased interstitial markings at follow-up pneumonia. ULDCT showed lesion suspected for lung carcinoma
9. CXR with unsure diagnosis of pneumonia. ULDCT confirmed diagnosis of pneumonia
10. CXR showed 14 mm nodule suspected for malignancy. ULDCT definitely confirmed an intrapulmonary 11×10 mm nodule with pleural tail. Furthermore, there was exclusion of enlarged lymph nodes, and diagnosis of a rib lesion
11. CXR showed basal rest lesion possible after pneumonia, unclear. ULDCT showed a fibrotic rest lesion
12. CXR showed a right basal mass and bilateral pleural effusion. ULDCT showed a second lesion in the right upper lobe and better definition of pleural effusion
13. CXR showed consolidations in the middle lobe and lingual and possible bronchial wall thickening. ULDCT showed additional consolidations in lower lobes, with mucus plugs and tree-in-bud nodules, but excluded bronchial wall thickening
14. CXR showed decrease of pleural effusion with follow-up. ULDCT showed no pleural effusion but rest lesion after pneumonia
15. CXR showed a wide mediastinum, and mass at right hilum or aorta could not be excluded. ULDCT excluded a mass and confirmed a mild ascending aorta aneurysm of 43 mm
16. CXR and ULDCT both showed fibrosis with rheumatoid arthritis or due to methotrexate use. ULDCT additionally showed substantial emphysema not observed with CXR
17. CXR and ULDCT both showed lingula and middle lobe atelectasis. ULDCT showed additional mucus plugs and bronchus wall thickening not observed with CXR, and excluded tumor
18. CXR and ULDCT both excluded interstitial lung disease. With CXR, 2 nodules were observed, and it is unclear whether their location was intrapulmonary, unclear diagnosis. ULDCT showed multiple intrapulmonary lymph nodes
19. CXR showed unchanged interstitial lung disease. ULDCT showed new consolidations, possible pneumonia, or cryptogenic organizing pneumonia not observed on CXR
20. CXR showed no change with lung carcinoma. ULDCT showed multiple lung nodules not observed on CXR
21. CXR showed possible pleural effusion on the right in a patient suspected for infection. ULDCT showed multiple lung nodules 4×10 and 1×20 mm not observed with CXR
22. CXR and ULDCT both showed emphysema. CT showed additional signs of pulmonary artery hypertension
23. CXR and ULDCT both showed subsegmental atelectasis. ULDCT additionally excluded airway obstruction or lymph nodes

Cases wherein ULDCT excluded diagnoses suggested on CXR (5 patients)
1. CXR showed possible enlarged hilum. ULDCT excluded congestive cardiac failure or lung disease
2. CXR showed increase of known consolidations. ULDCT excluded increase
3. CXR showed bronchial wall thickening. ULDCT showed normal airways without thickening
4. CXR showed partly resorbed pneumonia with atelectasis. ULDCT showed no pneumonia
5. CXR and ULDCT both excluded pneumonia. CXR showed possible bronchial wall thickening that was excluded by ULDCT

change in patient handling or advice. For the entire study group, there were no cases with CXR reported as having higher confidence than ULDCT.

## DISCUSSION

This prospective study shows, in patients referred for CXR for diagnosing chest pathology, that ULDCT performed at an effective dose similar to the dose for CXR, resulted in added value as compared with CXR. Diagnostic yield was caused by pathology that was not seen on CXR but was observed on ULDCT, pathology suspected on CXR that was excluded by ULDCT, and other relevant findings on ULDCT not seen on CXR, with much better perceived confidence for ULDCT as compared with CXR. Management effect in 20% of patients included expected change in therapy or follow-up, or avoiding of a (normal dose) CT. A strength of our study was that evaluation was performed within the regular clinical radiologic routine, with intention to diagnose, and with radiologic decision-making at the time of evaluation.

Current CT techniques allow for acquisitions at a very low effective dose. In this study, the difference in effective dose between CXR (0.040 mSv) and ULDCT (0.071 mSv) was small and negligible considering the mean effective dose of 0.10 mSv for CXR in Europe.[4] Compared with the typical effective doses for routine CT chest in Europe (~5.5 mSv) and the United States (~8 mSv), our ULDCT dose is 77 to 113 times (2 orders of magnitude) lower.[4,22] Techniques such as using tube current modulation for ULDCT acquisitions and iterative reconstruction techniques[23,24] may reduce the effective dose even further. The effective dose of 0.071 mSv for ULDCT will not be a limiting factor for introducing ULDCT of the chest on a broad scale in clinical practice.

The short 3 minutes in-room time for ULDCT was, among other aspects, made possible by skipping the acquisition of 2 scanograms and by the simple and fast acquisition protocol. Although the in-room time was longer for ULDCT than for CXR, the 3-minutes in-room time for ULDCT may allow high ULDCT throughput.

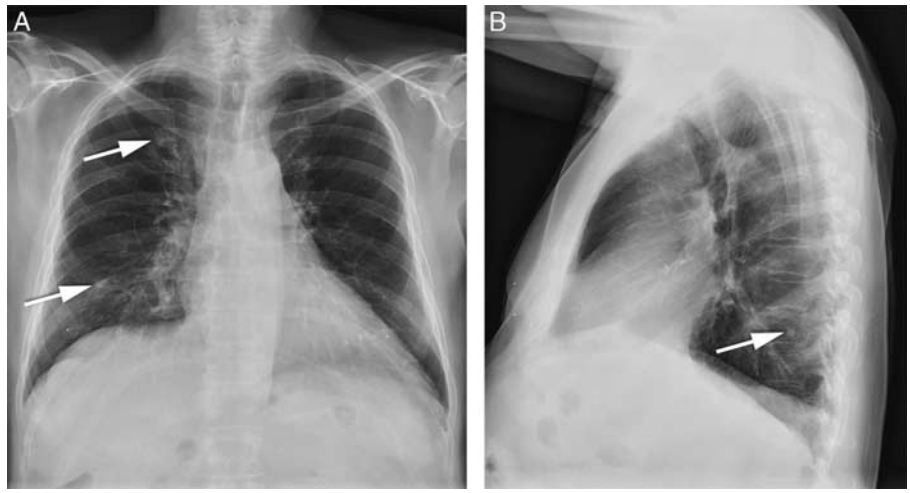


**FIGURE 3.** A 70-year-old male patient with myasthenia gravis autoimmune disease. The clinical question was "pathology?" CXR posteroanterior (A) and lateral (B) projections. Two nodules project on the posteroanterior image (arrows), one possibly in the lower lobe on the lateral view (arrow) but for the other with location unsure (intrapulmonary or not), and the morphology could not be characterized. CXR perceived confidence was 50% for presence of intrapulmonary nodules. On CXR, there were no signs of thymus enlargement, although this could not be excluded. In-room time was 96 seconds, effective dose was 0.04 mSv.

The actual diagnostic difference between CXR and ULDCT was larger than was suggested by the perceived confidence of 88% for CXR and 98% for ULDCT. This means that the perceived confidence for diagnosis was considerably overestimated for CXR, given the large number of false negatives and false positives with CXR, as well as additional findings on ULDCT that had management effect after ULDCT, because ULDCT was rated as having higher confidence for clinical diagnosis than CXR by the radiologist.

The prospect of ULDCT has previously been evaluated in a 130-patient group with acute dyspnea in the emergency setting. Although the subjective image quality of ULDCT ($0.182 \pm 0.028$ mSv) was rated slightly lower when compared with low-dose CT ($1.164 \pm 0.028$ mSv), the diagnostic confidence was rated as "certain" for ULDCT in all patients.[25] In a prospective clinical study comparing ULDCT with CXR in 231 patients after curative resected lung cancer, ULDCT had a higher negative predictive value than CXR for the diagnosis of new or recurrent lung cancer, wherein the majority of new or recurrent cancer was detected by ULDCT at an asymptomatic phase.[26] The effective doses in that study were 0.16 mSv for CXR and 0.2 mSv for ULDCT, approximately double the dose as in our study. Accordingly, our study demonstrates that ULDCT with effective dose below 0.1 mSv and similar to CXR, may be useful to replace CXR in a general population referred for an unselected variety of clinical indications as well. Some studies have recognized diagnostic limitations for ULDCT, especially with regard to chest evaluation in obese patients,[15] and/or the evaluation of emphysema, air trapping, or small ground-glass opacity nodules.[27] As increased noise reduces image quality, the studies suggested that ULDCT may not be used to replace low-dose or standard-dose CT for these indications.[15,27] However, our study design was different, as we compared ULDCT with CXR. Instead, we have shown that ULDCT provides very good images, as compared with CXR to detect chest disease, with much better perceived confidence for diagnosis, with effective dose comparable to CXR. Moreover, although body mass index (BMI) 30 kg/m$^2$ or more was an exclusion criterion in our study, ULDCT may still be expected to perform better than CXR because of x-ray scatter and anatomic tissue superposition in CXR examinations.

## Clinical Implications

ULDCT for diagnosing chest pathology has added value, as compared with CXR, in a patient population that was referred for CXR by outpatient clinics or general practitioners. ULDCT can be performed at an effective dose to the patient similar to the effective dose of CXR. ULDCT dose as well as the ULDCT in-room time will not be limiting factors for introducing ULDCT of the chest on a broad scale in clinical practice.

## Limitations of the Study

Our study had several limitations. Inclusion was limited to outpatients of at least 50 years of age, as humans at the age of 50 years or older are significantly less sensitive for exposure to ionizing radiation compared with younger individuals.[28] We do not know what the outcome would be for the younger patients. Reading CXR before ULDCT may have induced bias to the disadvantage of CXR. Radiologists evaluated images separately; this could represent a study bias. We did not follow-up patients after clinical reporting other than feedback initiated by the referrer, because our focus was to assess potential ULDCT value for diagnosis at the moment of referral for CXR. Moreover, we did not evaluate what the possible health gain in quality-adjusted life years would be with ULDCT, as compared with CXR with regard to possible (increase in) costs.[29] Further and larger prospective studies are needed to evaluate this important issue.

In conclusion, ULDCT provided added value by improved perceived confidence with reducing false-positive and false-negative CXR investigations, which had management implications in 20% of patients. The effective dose of ULDCT will not be a limiting factor for introducing ULDCT of the chest on a broad scale in clinical practice.

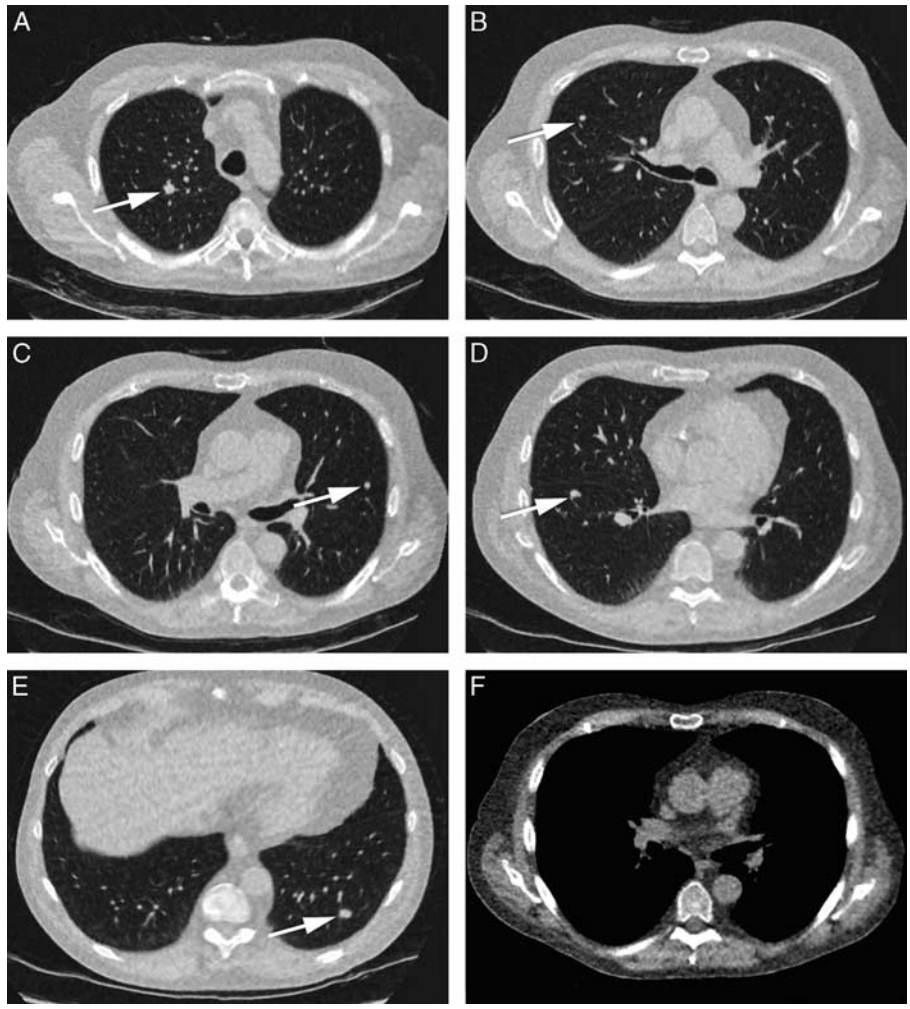


**FIGURE 4.** Same patient as in Figure 3. ULDCT from below, showing multiple intrapulmonary smooth-walled nodules with certainty that were indeterminate on CXR (A–E, arrows). Differential diagnosis was nodules due to the autoimmune disease, or use of azathioprine medication, or infectious. Thymus hyperplasia or thymoma was excluded (F). ULDCT perceived confidence for diagnosis was 100%. ULDCT provides more information with better confidence. In-room time was 156 seconds, effective dose was 0.08 mSv.

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