Original article

Prospective evaluation of thoracic diseases using a compact flat-panel detector spiral computed tomographic scanner

Da Som Kim, Seung-Jin Yoo, Jung Hee Hong, Nakwon Kwak, Jae-Joon Yim, Soon Ho Yoon

Department of Radiology, Inje University Busan Paik Hospital, Inje University College of Medicine, Busan, South Korea
Department of Radiology, Hanyang University Medical Center, Hanyang University College of Medicine, Seoul, South Korea
Department of Radiology, Keimyung University School of Medicine, Daegu, South Korea
Division of Pulmonary and Critical Care Medicine, Department of Internal Medicine, Seoul National University Hospital, Seoul, South Korea
Department of Internal Medicine, Seoul National University College of Medicine, Seoul, South Korea
Department of Radiology, Seoul National University Hospital, Seoul National University College of Medicine, Seoul, South Korea

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ABSTRACT

Objective: To prospectively evaluate the image quality and diagnostic performance of a compact flat-panel detector (FD) scanner for thoracic diseases compared to a clinical CT scanner.

Materials and methods: The institutional review board approved this single-center prospective study, and all participants provided informed consent. From December 2020 to May 2021, 30 patients (mean age, 67.1 ± 8.3 years) underwent two same-day low-dose chest CT scans using clinical state-of-art and compact FDCT scanners. Image quality was assessed visually and quantitatively. Two readers evaluated the diagnostic performance for nodules, parenchymal opacifications, bronchiectasis, linear opacities, and pleural abnormalities in 40 paired CT scans. The other 20 paired CT scans were used to examine the agreement of semi-quantitative CT scoring regarding bronchiectasis, bronchiolitis, nodules, airspace consolidations, and cavities.

Results: FDCT images had significantly lower visual image quality than clinical CT images (all \( p < 0.001 \)). The two CT image sets showed no significant differences in signal-to-noise and contrast-to-noise ratios (56.8 ± 12.5 vs. 57.3 ± 15.2; \( p = 0.985 \) and 62.9 ± 11.7 vs. 60.7 ± 16.9; \( p = 0.615 \)). The pooled sensitivity was comparable for nodules, parenchymal opacifications, linear opacities, and pleural abnormalities (\( p = 0.065-0.625 \)), whereas the specificity was significantly lower in FDCT images than in clinical CT images for micronodules (\( p = 0.007 \)) and bronchiectasis (\( p = 0.004 \)). The specificity was mostly 1.0. Semi-quantitative CT scores were similar between the CT image sets (\( p > 0.05 \)), and intraclass correlation coefficients were around 0.950 or higher, except for bronchiectasis (0.869).

Conclusion: Compact FDCT images provided lower image quality but comparable diagnostic performance to clinical CT images for nodules, parenchymal opacifications, linear opacities, and pleural abnormalities.

1. Introduction

Chest CT is an essential imaging modality to evaluate pulmonary diseases in modern medicine and plays a salient role in managing the COVID-19 pandemic [1,2]. Nevertheless, extant clinical CT machines have limited mobility and require substantial efforts and complex sanitizing measures to scan both patients with and without infectious pulmonary diseases such as COVID-19 [3]. Compact flat-panel detector (FD) CT machines are smaller than clinical CT machines and are mobile, as they are typically equipped with a C-arm [4]. FD CT machines may be deployed rapidly to respond to outbreaks of infectious diseases for exclusive point-of-care (POC) diagnostic use in patients with contagious...
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2. Materials and methods

2.1. Patients

This single-arm prospective trial was approved by our institutional review board, and informed consent was obtained from all participants. The study protocol was registered in the Korean Clinical Information Service (Registration Number: KCT0005633).

2.2. Patients

We applied the following inclusion criteria to determine eligibility from December 2020 to May 2021: a) adult patients 20 years or older who were suspected of having pulmonary disease; b) patients who planned to undergo chest CT scans electively; and c) patients who fully understood the content of this trial and provided informed consent. We excluded women who were pregnant or might become pregnant. A study coordinator collected baseline characteristics of the enrolled patients, including age, sex, body mass index (BMI), and smoking history, from the electronic medical record system.

2.3. CT acquisition

2.3.1. Conventional low-dose CT scans

All low-dose chest CT scans were performed using an up-to-date flagship multidetector CT scanner (Somatom Force, Siemens Healthineers, Erlangen, Germany) with gantry dimensions of 1.99 × 1.18 × 2.40 m³. The CT scans were obtained at full inspiration and served as reference images. The scanner’s size and weight were 3.27 × 1.99 × 1.18 m³ and 3150 kg, respectively. The minimum space for CT deployment was 11.6 × 4.5 m². The following CT parameters were used in clinical practice: tube voltage, Sn100 kVp without CARE kVp; quality reference tube current, 130 mAs with CAREDose4D; scan fields of view, 50 × 50 cm; matrix, 512 × 512; rotation time, 0.25 s/rotation; detector collimation, 192 × 0.6 mm; and pitch, 3, indicating that a whole lung was typically scanned within one second. All CT scans were reconstructed using advanced modeled iterative reconstruction algorithms into 1-mm axial images with a soft tissue kernel (Br40–3) and 1-mm axial images with a sharp kernel (Br59–3). The craniocaudal scan covered the area from the lower neck to the costophrenic angle in a single breath-hold.

2.3.2. Compact POC FD low-dose CT scans

After conventional CT scanning for clinical purposes, additional ultra-low CT scans for research purposes were subsequently taken on the same day using a compact FD spiral CT scanner (Smart M, Vatech, Gyeonggi-do, South Korea) with gantry dimensions of 1.24 × 0.73 × 1.57 m³. The scanner’s size and weight were 1.24 × 2.38 × 1.57 m³ and 600 kg, respectively. The minimum space for CT deployment was 3.5 × 2 m². The CT machine was located close to the clinical CT machine, within 1 min on foot. The fixed CT parameters were used as follows: tube voltage, 120 kVp; tube current, 10 mAs; scan field of view, 42 × 30 cm; matrix, 500 × 217; rotation time, 1 s/rotation; detector collimation, 5.3 mm; and pitch, 1.0, indicating that a whole lung was scanned in around 30 s in total. All CT scans were reconstructed using iterative reconstruction algorithms into 1-mm axial images with a soft tissue kernel. The craniocaudal scan covered the area from the lung apex to the costophrenic angle level in two breath-holds, as the CT scanning in a single breath-hold could cover approximately 16 cm.

2.4. Qualitative image quality evaluation

Two thoracic radiologists (J.H.H. and S.J.Y., with 6–7 years of experience in chest CT interpretation) independently evaluated the image quality of the low-dose CT images. The readers reviewed a total of 60 CT scans (30 clinical and 30 FD CT scans, each) in a random order to grade overall image quality, image noise, presence of artifact, and depiction of normal structure. They were blinded to clinical information and CT scanners. Detailed information on the scale used for image quality assessment is provided in Supplementary Table 1.

2.5. Quantitative image quality assessment

One thoracic radiologist (S.H.Y., with 16 years of experience in body CT interpretation) analyzed objective image quality by measuring the signal-to-noise ratio (SNR) and the contrast-to-noise ratio (CNR). For SNR analysis, the radiologist manually drew a total of six round regions of interest (ROIs) in the right and left lung parenchyma per CT scan at the level of the aortic arch, hilum, and inferior pulmonary vein, while avoiding pulmonary lesions, bronchi, and vessels. The reader reviewed the clinical and FD low-dose CT scans side-by-side on a picture archiving and communication system to place the ROIs identically on both CT scans. The ROIs were maintained between 50 and 100 mm². For CNR analysis, the reader placed round ROIs in the main pulmonary trunk and the largest pulmonary lesion if a 10-mm or larger lesion existed.

2.6. Quantitative assessment of lesion detectability

Two thoracic radiologists (J.H.H. and S.J.Y) independently identified parenchymal abnormalities in 40 paired CT scans from 20 patients, with the exclusion of 20 scans from 10 patients with confirmed non-tuberculous mycobacterial (NTM) lung disease. A total of 40 paired CT scans were assigned randomly, regardless of the pair. After reviewing half of the CT scans, readers reviewed the rest in two weeks to reduce potential recall bias.

The reviewers detected and recorded lesions characteristics and locations: nodules (micronodules [3 mm or smaller] and nodules), parenchymal opacifications (ground-glass opacities and consolidations), bronchiectasis, linear opacities (fibrotic scurs, mucus plugs, atelectasis, and reticular opacities), and pleural lesions (pleural effusion or thickening). The other two thoracic radiologists (D.S.K. with a 6-year experience of CT interpretation and S.H.Y.) reviewed the CT images in consensus and prepared reference judgments. Then, the identified lesion records were matched with the reference data.

In total, 100 pulmonary lobes in 20 patients (five lobes per patient) were evaluated for lesion detectability. Sensitivity was defined as the proportion of lesions that matched between the identified lesions and the reference. Multiple lesions in the same lobe were individually counted. Specificity was defined as the proportion of lobes without abnormalities that matched between the identified lesions and the reference.

2.7. Quantitative assessment of lesion extent

Ten of 30 patients had NTM lung disease, which tended to have an extensive distribution, hampering the assessment of lesion detectability. Their CT scans were used to determine whether compact FD low-dose CT scans could be suitable for quantifying the extent of various parenchymal abnormalities. The two radiologist readers independently graded the extent of parenchymal abnormalities in a semi-quantitative
manner regarding bronchiectasis, cellular or inflammatory bronchiolitis, nodules of 10–30 mm in diameter, airspace consolidation, and cavities based on the NTM CT scoring system proposed by Kim et al. [6]. In the system, the CT scores reflect the severity of lung involvement in NTM pulmonary diseases. The mean CT score in each patient was calculated by averaging the CT score in the pulmonary lobes. A total of 20 paired scans were randomly assigned regardless of the pair. Readers first reviewed 10 CT scans and reviewed the rest in two weeks to reduce potential recall bias.

3. Statistical analysis

The normality of the distribution of continuous variables was tested using the Kolmogorov-Smirnov test. The paired t-test and Wilcoxon signed-rank test were used for continuous variables after normality testing to compare the qualitative and quantitative image quality parameters between CT machines. Interobserver agreement was evaluated using intraclass correlation coefficients (ICCs) with a two-way model for each qualitative analysis item: 0.76–1.0, excellent agreement; 0.40–0.75, fair to good agreement; and < 0.40, poor agreement. Bland-Altman analyses were used to assess the agreement between the CT machines. The McNemar test was used to compare the sensitivity and specificity of clinical and compact FD low-dose CT scans. All statistical analyses were performed using the IBM SPSS Statistics 26.0 software package (IBM Corp., Armonk, NY, USA). P-values < 0.05 were considered statistically significant.

4. Results

4.1. Patient characteristics

Patient characteristics are shown in Table 1. The 30 patients agreed to undergo additional FD CT scans to clinical CT scans and included 12 men (mean age, 67.1 ± 8.3 years; age range, 51–79 years) and 18 women (mean age, 62.8 ± 10.5 years; age range, 43–83 years). The mean BMI was 20.8 kg/m² (range, 12.8–29.8 kg/m²). Of these 30 patients, five had a history of smoking and 10 had received a diagnosis of NTM lung disease. Four participants were suspected of having NTM lung disease in a limited extent of the lung parenchyma, but without pathological confirmation.

4.2. Qualitative comparison of image quality

Both readers gave better scores to the clinical CT images than to the compact FD CT images in terms of all image quality parameters (Table 2): overall image quality (4.34 ± 0.81 vs. 2.37 ± 0.60; p < 0.001), image noise (4.40 ± 0.76 vs. 2.93 ± 0.80; p < 0.001), motion and streak artifacts (4.45 ± 0.79 vs. 2.67 ± 0.87; p < 0.001), depiction of intrapulmonary vessels and the lobar fissure (4.79 ± 0.69 vs. 3.28 ± 0.82; p < 0.001), depiction of mediastinal structures (4.54 ± 0.79 vs. 2.76 ± 0.56; p < 0.001), and depiction of bronchial structures (4.65 ± 0.74 vs. 3.34 ± 0.99; p < 0.001). The CT scores did not significantly differ according to sex and BMI (Supplementary Table 2).

4.3. Quantitative comparison of image quality

There was no significant difference in the SNR and CNR between clinical and compact FD low-dose CT scans (mean SNR: 56.8 ± 12.5 vs. 57.3 ± 15.2, p = 0.985; lesion CNR: 62.9 ± 11.7 vs. 60.7 ± 16.9, p = 0.615) (Table 3).

4.4. Sensitivity and specificity of lesion detection

In 20 patients, a total of 165 lesions were identified: 27 micronodules, 40 nodules, 30 parenchymal opacifications (23 consolidations and 7 ground-glass opacities), 46 cases of bronchiectasis, 16 linear opacities, and six pleural abnormalities (Table 4). The detection rate of parenchymal opacifications was higher than the detection rates of other findings for both clinical and compact FD low-dose CT images (Fig. 1). The pooled sensitivity of the clinical CT images was significantly higher than that of the compact FD CT images in terms of micronodules (0.83 [45/54] vs. 0.61 [33/54]; p = 0.007) (Fig. 2) and bronchiectasis (0.91 [84/92] vs. 0.77 [71/92]; p = 0.004) (Fig. 3). There were two false-positive micronodules on compact FD CT images in one reader, in which the pulmonary vessels were mistaken due to a motion artifact and poor image quality, respectively.

4.5. Correlation and reproducibility of NTM CT scoring

There was no significant difference in NTM scores between the clinical and compact FD low-dose CT images (p > 0.05) regarding the total score and each item of bronchiectasis, cellular bronchiolitis, nodules, consolidations, and cavities (Table 5, Fig. 4). The ICCs between the

| Table 1 | Baseline patient characteristics. |
|------------------|-------------------------------|
| Patient characteristics | Value |
| Age | 64.5 (43–79) |
| Sex | Men: 12 (40 %); Women: 18 (60 %) |
| Height | 162.1 (145-183) |
| Weight | 55.1 (32–88) |
| Body mass index (kg/m²) | 20.8 (12.8–29.8) |
| Smoking | Non-smoker: 25 (83.7 %); Current or former smoker: 5 (16.7 %) |
| Diagnosis | NTM lung disease: 10; M. avium: 5; M. intracellulare: 3; M. abscessus: 2; M. iranicum: 1; Suspected NTM lung disease: 4; Bronchiectasis with bronchiolitis: 2; Healed tuberculosis: 4; Suspected interstitial lung disease: 3; Chronic pulmonary aspergillosis: 1 |

Data in parentheses indicate data range or proportion. NTM=nontuberculous mycobacterial.

| Table 2 | Qualitative comparison of image quality between clinical and compact flat-panel detector low-dose CT scans. |
|------------------|-------------------------------|
| Clinical LDCT | Compact FD LDCT | P- value | ICC [95 % CI] |
| Overall image quality | 4.34 ± 0.81 | 2.37 ± 0.60 | < 0.001 | 0.88 [0.80, 0.93] |
| Image noise | 4.40 ± 0.76 | 2.93 ± 0.80 | < 0.001 | 0.76 [0.59, 0.85] |
| Motion and streak artifacts | 4.45 ± 0.79 | 2.67 ± 0.87 | < 0.001 | 0.86 [0.77, 0.92] |
| Depiction of intrapulmonary vessels and lobar fissure | 4.79 ± 0.69 | 3.28 ± 0.82 | < 0.001 | 0.90 [0.85, 0.94] |
| Depiction of mediastinal structures | 4.54 ± 0.79 | 2.76 ± 0.56 | < 0.001 | 0.85 [0.75, 0.91] |
| Depiction of bronchial structures | 4.65 ± 0.74 | 3.34 ± 0.99 | < 0.001 | 0.83 [0.72, 0.90] |

LDCT=low-dose CT; FD=flat-panel detector; ICC=intraclass correlation coefficient; CI=confidence interval.
CT images were roughly 0.950 or higher for the total score and each item, except bronchiectasis (0.869). The 95% limits of agreement in CT scores between the CT images were 0.95–2.52 in assessing bronchiectasis, and the 95% limits of agreement for other items were smaller than ±1. The 95% limits of agreement of the total CT score between clinical CT and compact FD CT images were 0.92–2.83 (Supplementary Figure 1), and bronchiectasis preferentially contributed to the degree of difference in the total CT score between the CT image sets.

### 4.6. CT radiation dose

The mean volume CT dose index and dose-length products were 0.5 mGy and 18.2 ± 1.6 mGy cm in the clinical low-dose CT scans, and the corresponding values were 2.5 mGy and 57.7 mGy cm in the compact FD low-dose CT scans ($p < 0.001$).

### Table 3
Quantitative comparison of image quality between clinical and compact flat-panel detector low-dose CT scans.

|                      | Clinical LDCT | Compact FD LDCT | P-value |
|----------------------|---------------|-----------------|---------|
| **Contrast-to-noise ratio** |               |                 |         |
| Lesion               | 62.9 ± 11.7   | 60.7 ± 16.9     | 0.615   |
| Main pulmonary artery| 59.5 ± 12.9   | 58.3 ± 14.4     | 0.239   |
| **Signal-to-noise ratio** |               |                 |         |
| Right upper lobe     | 59.3 ± 17.5   | 53.1 ± 23.5     | 0.150   |
| Left upper lobe      | 58.6 ± 16.5   | 66.2 ± 24.0     | 0.112   |
| Right middle lobe    | 62.6 ± 19.7   | 62.2 ± 22.7     | 0.940   |
| Left lingula         | 62.6 ± 16.4   | 71.7 ± 24.9     | 0.063   |
| Right lower lobe     | 54.1 ± 19.3   | 59.0 ± 24.0     | 0.286   |
| Left lower lobe      | 59.9 ± 20.0   | 61.9 ± 27.4     | 0.695   |
| Mean                 | 56.8 ± 12.8   | 57.3 ± 15.2     | 0.985   |

LDCT=low-dose CT; FD=flat-panel detector.

### Table 4
Sensitivity and specificity for lesion detectability between clinical and compact flat panel detector low dose CT scans.

|                      | Clinical LDCT | Compact FD LDCT | P-value |
|----------------------|---------------|-----------------|---------|
|                      | Reader 1      | Reader 2        | Pooled reader | Reader 1 | Reader 2 | Pooled reader | Reader 1 | Reader 2 | Pooled reader | Reader 1 | Reader 2 | Pooled reader | Reader 1 | Reader 2 | Pooled reader | P-value |
| **Sensitivity**      |               |                 |             |         |         |             |         |         |             |         |         |             |         |         |             |        |
| Micronodules (≤3 mm) | 0.89 (24/27)  | 0.78 (21/27)    | 0.83 (45/54) | 0.67 (18/27) | 0.56 (15/27) | 0.61 (33/54) | 0.007   |
| Nodule               | 0.73 (29/40)  | 0.63 (25/40)    | 0.68 (54/80) | 0.60 (24/40) | 0.63 (25/40) | 0.61 (49/80) | 0.648   |
| Parenchymal opacification | 0.97 (29/30) | 0.87 (26/30)    | 0.92 (55/60) | 0.90 (27/30) | 0.77 (23/30) | 0.83 (50/60) | 0.125   |
| Bronchiectasis       | 0.93 (43/46)  | 0.89 (41/46)    | 0.91 (84/92) | 0.85 (39/46) | 0.70 (32/46) | 0.77 (61/92) | 0.004   |
| Linear opacity       | 0.69 (11/16)  | 0.69 (11/16)    | 0.69 (22/32) | 0.50 (8/16)  | 0.44 (7/16)  | 0.47 (15/32) | 0.065   |
| Pleural effusion or thickening | 0.83 (5/6) | 0.83 (5/6) | 0.83 (10/12) | 1.00 (6/6) | 0.33 (2/6) | 0.67 (8/12) | 0.625   |
| **Specificity**      |               |                 |             |         |         |             |         |         |             |         |         |             |        |
| Micronodules (≤3 mm) | 1.00 (74/74)  | 1.00 (74/74)    | 1.00 (148/148) | 0.97 (72/74) | 1.00 (74/74) | 0.99 (146/148) | 0.125   |
| Nodule               | 1.00 (71/71)  | 1.00 (71/71)    | 1.00 (142/142) | 1.00 (71/71) | 1.00 (71/71) | 1.00 (142/142) | 1.000   |
| Parenchymal opacification | 1.00 (71/71) | 1.00 (71/71) | 1.00 (142/142) | 1.00 (71/71) | 1.00 (71/71) | 1.00 (142/142) | 1.000   |
| Bronchiectasis       | 1.00 (54/54)  | 1.00 (54/54)    | 1.00 (108/108) | 1.00 (54/54) | 1.00 (54/54) | 1.00 (108/108) | 1.000   |
| Linear opacity       | 1.00 (84/84)  | 1.00 (84/84)    | 1.00 (168/168) | 1.00 (84/84) | 1.00 (84/84) | 1.00 (168/168) | 1.000   |
| Pleural effusion or thickening | 1.00 (94/94) | 1.00 (94/94) | 1.00 (188/188) | 1.00 (94/94) | 1.00 (94/94) | 1.00 (188/188) | 1.000   |

LDCT=low-dose CT; FD=flat-panel detector.

**Fig. 1.** Clinical and compact flat-panel detector low-dose CT images in a 75-year old woman. Clinical (A,C) and compact flat-panel detector low-dose CT (B,D) images show nodular consolidation (arrows) and branching opacities (arrowheads) in the right upper and lower lobes. The clinical CT images had better quality than the flat-panel detector CT images, but both sets of CT images depicted all parenchymal abnormalities.
This prospective study showed that compact FD low-dose CT images had visually lower but quantitatively comparable image quality to clinical state-of-the-art low-dose CT images. Regarding lesion detectability, the FD CT images were significantly inferior for visualizing micronodules and bronchiectasis, whereas nodules, parenchymal opacifications, linear opacities, and pleural lesions were equally to nonsignificantly less frequently depicted. In addition, the evaluation of the extent of various NTM abnormalities on the FD CT images tended to be lower for bronchiectasis and comparable for cellular bronchiolitis, cavities, nodules, and consolidations. Those results indicate that the FD low-dose CT images provided sufficient diagnostic capability for most parenchymal abnormalities with increased density, but were insufficient to depict minute nodules and bronchiectasis due to their lower image quality and the presence of artifacts.

FD CT images have the potential to be deployed promptly as a POC diagnostic tool when the next pandemic occurs. Viral pneumonia is responsible for recent major pandemics and will likely account for the next pandemic [7,8]. Viral pneumonia usually shows diffuse lung involvement, and its CT findings mainly comprise ground-glass opacities, consolidation, and nodules [9]. Those findings generally could be depicted on the FD low-dose CT scans. Furthermore, the weight and the minimum space of FD CT scanner are one-fifth or less of clinical CT scanners. FD CT scanners use a standard household voltage, whereas clinical scanners typically require a power generator. In particular, the smaller size and weight are advantageous in intensive care units where radiologic examinations are indicated in patients at risk for deterioration [1], but are less accessible in the pandemic setting.

The mean CT radiation dose of the FD CT images was less than 3 mGy, but five times higher than that of the clinical CT images. The tube voltage and the tube current of the FD CT scans were 120 kVp and 3 mGy, but five times higher than that of the clinical CT images. The higher CT radiation despite the low-exposure parameters in the FD CT images seems to be associated with longer radiation exposure. The FD CT scanning required two sequential scans of the upper and lower thoraces, which took around 30 s in total due to lower image efficiency and

Table 5  
Correlation and reproducibility for NTM CT scoring between clinical and compact flat panel detector low dose CT scans.

|                | Mean CT score | Correlation | Measurement difference |
|----------------|---------------|-------------|------------------------|
|                | Clinical LDCT | Compact FD LDCT | P value | ICC 95 % CI | P value | Mean ± SD | 95 % limits of agreement |
| Bronchiectasis | 5.2 ± 1.3     | 4.4 ± 1.3   | < 0.001 | 0.869 0.670 0.948 | < 0.001 | 0.79 ± 0.89 | -0.95 -2.52 |
| Cellular bronchiolitis | 4.6 ± 1.7 | 4.4 ± 1.7 | 0.307 | 0.987 0.968 0.995 | < 0.001 | 0.12 ± 0.39 | -0.64 -0.88 |
| Cavity | 2.7 ± 3.6 | 2.7 ± 3.6 | 1.000 | 1.000 1.000 1.000 | NA | 0.00 ± 0.00 | 0.00 -0.00 |
| Nodule | 0.4 ± 0.5 | 0.4 ± 0.5 | 0.317 | 0.946 0.865 0.979 | < 0.001 | 0.05 ± 0.22 | -0.39 -0.49 |
| Consolidation | 1.1 ± 1.0 | 1.1 ± 1.0 | 1.000 | 1.000 1.000 1.000 | NA | 0.00 ± 0.00 | 0.00 -0.00 |
| Total score | 14.0 ± 6.3 | 13.0 ± 6.5 | < 0.001 | 0.994 0.986 0.998 | < 0.001 | 0.96 ± 0.96 | -0.92 -2.83 |
| Total score except bronchiectasis | 8.8 ± 5.5 | 8.6 ± 5.5 | 0.171 | 0.998 0.996 0.999 | < 0.001 | 0.17 ± 0.43 | -0.68 -1.02 |

LDCT=low-dose CT; FD=flat-panel detector; ICC=intraclass correlation coefficient; CI=confidence interval; SD=standard deviation; NA=Not applicable.

5. Discussion

Fig. 2. Clinical and compact flat-panel detector low-dose CT images in a 64-year old woman with nontuberculous mycobacterial lung disease. A clinical low-dose CT image (A) shows multiple clustered tiny nodules in the right middle lobe and bronchiectasis in the left lingula. The multiple tiny nodules (arrows) on the clinical CT image were poorly visualized on a compact flat-panel CT image (B) due to the limited spatial resolution.

Fig. 3. Clinical and compact flat-panel detector low-dose CT images in a 71-year old man with interstitial lung disease. A clinical low-dose CT image (A) shows reticular opacities, traction bronchiectasis (arrow), and ground-glass opacities in the bilateral peripheral lungs. A compact flat-panel detector low-dose CT image (B) suffered from respiratory motion and streak artifacts. The two readers inconsistently assessed the presence of traction bronchiectasis in multiple lobes on flat-panel detector CT images.
temporal resolution. Nevertheless, these two factors have room for improvement, and an updated version of the FD CT scanner enabled improved efficiency by using better reconstruction and faster rotation of FD (not shown).

This study has several limitations. The number of patients was relatively small, and it was challenging to enroll more patients even without COVID-19 in the middle of the COVID-19 pandemic. We could not apply FD CT scanning in patients with COVID-19 as it required complex sanitation procedures, and departmental policy did not allow FD CT scanning for research purposes during the pandemic. Besides, our study population did not include patients with acute pneumonia. Before applying FD CT scanning to such patients, it was required to first examine if FD CT scans were feasible for patients with non-acute pulmonary diseases. Our results warrant further extensive validation, and we are about to begin the next prospective investigation in patients with acute pneumonia with the upgrade FD CT scanner. We could not evaluate parenchymal abnormalities with decreased density, such as emphysema or air-trapping. Moreover, we did not evaluate the diagnostic capability of the FD CT images for COVID-19 or viral pneumonia or whether their use would affect patient management in practice. Lastly, clinical low-dose CT scans used as reference images might have a limitation in evaluating ground-glass opacity or subtle abnormalities compared to standard-dose CT images. It was somewhat inevitable to minimize radiation exposure of sequential CT scanning to the enrolled patients under the ‘As Low As Reasonably Achievable’ principle, and our result warrants further validation.

In conclusion, the FD low-dose CT images provided visually lower image quality, but comparable detectability to clinical low-dose CT images for nodules and parenchymal opacifications. The current limitations of the FD CT images include a relatively higher CT radiation dose and a limited ability to detect bronchiectasis and micronodules. Nevertheless, considering the portability of FD CT scanners, FD low-dose CT scans may be a potential POC imaging tool in future pandemics.

**Ethical statement**

This single-arm prospective trial was approved by our institutional review board, and informed consent was obtained from all participants. The study protocol was registered in the Korean Clinical Information Service (Registration Number: KCT0005633).
Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.ejro.2022.100452.

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