Assessment of Chest High-Field Magnetic Resonance Imaging in Children and Young Adults With Noncystic Fibrosis Chronic Lung Disease

Comparison to High-Resolution Computed Tomography and Correlation With Pulmonary Function

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Objectives: Magnetic resonance imaging (MRI) has been proposed as a radiation-free alternative to high resolution computed tomography (HRCT) for the assessment and follow-up of chest disorders. Thus far, no study has compared the efficacy of high-field MRI and HRCT in children and adults with noncystic fibrosis (CF) chronic lung disease. The aims of our study were: (1) to assess whether chest high-field MRI is as effective as chest HRCT in identifying pulmonary abnormalities; and (2) to investigate the relationships between the severity and extent of lung disease, and functional data in patients with non-CF chronic lung disease.

Materials and Methods: Forty-one subjects (median age, 13.8 years; range, 5.9–29.3 years; 30 children/11 adults) with primary ciliary dyskinesia (n = 14), primary immunodeficiency (n = 14), or recurrent pneumonia (n = 13) underwent pulmonary function tests, chest HRCT (120 kV, dose-modulated mAs) and high-field 3.0-T MRI (HASTE; transversal orientation; repetition time/echo time/flip angle/acquisition time, infinite/92 milliseconds/150°/approximately 90 seconds). HRCT and MRI images were scored in consensus by 2 raters using a modified version of the Helbich scoring system. The maximal score was 25.

Results: HRCT and high-field MRI total scores were 11 (range: 1–20) and 11 (range: 1–17), respectively. There was good agreement between the 2 techniques for all scores ($r > 0.8$). HRCT and MRI total scores, and extent of bronchiectasis scores were significantly related to pulmonary function tests ($r = -0.4$, $P < 0.05$). The MRI mucous plugging score was significantly related to pulmonary function tests ($r = -0.4$, $P < 0.05$).

Conclusions: Chest high-field 3.0-T MRI appears to be as effective as HRCT in assessing the extent and severity of lung abnormalities in non-CF chronic lung diseases, and might be a reliable radiation-free option to HRCT.

Key Words: high-field MRI, HRCT, chronic lung disease, pulmonary function

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The last 2 decades have seen an increase in the prevalence of chronic lung disorders in children and adults. This is probably because of 2 factors. First, patients with cystic fibrosis (CF), which is the most frequent congenital chronic lung disease in white subjects, survive longer than in the past.[1] Second, thanks to new diagnostic tools, other pulmonary disorders, including non-CF bronchiectasis, primary ciliary dyskinesia (PCD), and interstitial lung disease, are now more easily identified.

Chest computed tomography (CT), particularly high-resolution CT (HRCT), has become the imaging technique of choice for the evaluation of lung abnormalities at any age.[2,3] However, CT has been criticized for its ionizing radiation burden and the possible consequences of cumulative doses, particularly in relation to frequent follow-up examinations in patients with chronic disorders, in pregnancy, and in children.[4] Therefore, the radiation dose during CT should be ideally tailored to the type of study being performed and to the size of the patient, a practice that is increasing but is by no means universal.[4] This issue is especially relevant in the pediatric setting because children are more sensitive to radiation than are adults.[5]

Chest magnetic resonance imaging (MRI) has been proposed as a radiation-free technique for the assessment and follow-up of several chest disorders.[6–12] However, its application in lung disease has long been limited by technical problems, namely a low signal-to-noise ratio because of the low proton density of the lung, and artifacts because of cardiac and breathing motion or to air/soft tissue transition.[13] Several studies have compared the efficacy of chest morphologic MRI, mainly 1.5-T MRI, and other traditional imaging techniques in children and adults with lung disorders.[9,11,14–21] The overall conclusion of these studies is that MRI is comparable to conventional chest x-ray and CT, thus indicating that chest MRI may be a reliable radiation-free option in lung disorders.[9,11,14–22]

High-field 3.0-T MRI has several advantages over 1.5-T MRI, namely, better temporal and/or spatial resolution and faster acquisition times.[15] To our knowledge, no study has compared chest HRCT to high-field MRI in children and adults with non-CF chronic lung disease. The primary aim of this study was to assess whether high-field 3.0-T MRI is as effective as HRCT in identifying pulmonary abnormalities in children and young adults with non-CF chronic lung disease. The secondary aim was to investigate the relationships between the severity and extent of lung structural changes, identified with HRCT and MRI, and pulmonary function tests (PFTs).

MATERIALS AND METHODS

Patients

Our institutional review board approved the study, and informed written consent was obtained from the parent/legal guardian of each child and from adult patients. Sixty-three patients with

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non-CF chronic lung disease were seen at our Department between March 2007 and June 2008. Twenty-two of them were excluded because of acute respiratory infection and/or mental retardation or other conditions that could compromise compliance to HRCT and MRI, namely, those with age less than 5 years and claustrophobic. Therefore, we prospectively enrolled in the study 41 subjects (25 males; median age, 13.8 years; range, 5.9–29.3 years; 30 children/11 adults) with chronic lung disorders because of PCD (group A; n = 14; 10 males; median age, 15.2 years; range, 10.4–29.3 years), to primary immunodeficiency (group B; n = 14; 9 males; median age, 13.4 years; range, 6.2–20.5 years), or to recurrent pneumonia (group C; n = 13; 6 males; median age, 11.1 years; range, 5.9–24.6 years). In all patients, CF had been previously excluded on the basis of normal sweat chloride test and negative results at CF gene mutation analysis for the most common mutations in our population, which accounted for 94% of mutant alleles found locally. In group A, PCD was suspected on the basis of clinical features and/or situs viscerum inversus.[23] Diagnosis was confirmed by light microscopy and by electron microscopy analysis of cilia ultrastructure on nasal brushing. Group B consisted of patients with primary immunodeficiency including chronic granulomatous disease (n = 6), hyper-IgM syndrome (n = 1), IgA deficiency (n = 2), common variable immunodeficiency (n = 3), and autosomal recessive (n = 1), or X-linked (n = 1) agammaglobulinemia. Patients from group C were diagnosed as having recurrent pneumonia, defined as ≥2 episodes in a single year or ≥3 episodes ever.[24] Nasal ciliary electron microscopy findings and detailed immunologic investigations were unremarkable in all group C subjects.

Patients underwent chest HRCT for clinical reasons, ie, persistence of chronic cough and/or focal abnormality at chest x-ray unresponsive to medical treatment, and/or discrepancy between lung function or clinical status and chest x-ray. In all patients chest MRI and HRCT were performed on the same day.

HRCT Scanning

The HRCT scan was performed with a 4-slice CT scanner (Aquilion, Toshiba, Japan) and a bodyweight adapted protocol (adolescents: 120 kV, 140 mAs; children over 45 kg: 120 kV, 65 mAs; children over 35 kg: 120 kV, 45 mAs; children below 35 kg: 120 kV, 30 mAs), with 1x4 mm collimation, 10 mm gap, 0.5 seconds rotation time, automatic exposure control, multiple inspiratory breath holds of 3 seconds each, with the patient in a supine position. Scanning extended from the lung apices to below the costophrenic angles. The field of view of each sequence was patient-adapted. Images were reconstructed using a high-resolution algorithm. The total time for acquisition of the images was approximately 5 minutes, including positioning of the patient. Contrast medium was not administered. For documentation of radiation exposure, the dose length product was recorded, and the effective dose (*E*) and the weighted CT dose index were calculated. A lung window setting (+1500/−500 Hounsfield unit) was used for image analysis. Images were reviewed on a workstation (iMac MacOS×10.4/OsiriX v.2.7.5 32 bit).

MR Scanning

MRI was performed with a 3.0-T MR scanner (Magnetom Trio, Siemens Erlangen, Germany), a maximum gradient strength of 40 mT/m, a slew rate of 200 mT/m/ms, and 32 radiofrequency channels. We used a dedicated 12-element integrated matrix coil system that covered the whole thorax for signal reception. It consisted of 1 anterior and 1 posterior flexible phased-array coil, each containing a set of 6 receiver elements. The applied sequence was a T2-weighted half-Fourier single-shot turbo spin-echo (HASTE) sequence, performed using an electrocardiograph-gating to reduce cardiac motion artifacts, and respiratory-gating by a navigator signal that monitored the diaphragm position. The field of view was patient-adapted. Sequence parameters were: repetition time/echo time/flip angle, infinite/92 milliseconds/150 degrees; 25 to 30 slices; slice thickness, 5 mm; distance factor, 20%; transversal orientation (matrix, 380 × 256); acquisition time, approximately 90 seconds. Parallel imaging was used for all measurements using the GRAPPA (Generalized Autocalibrating Partially Parallel Acquisition) algorithm with an acceleration factor of 2 and 24 reference lines. No patient required sedation. Door-to-door time was 5.5 minutes (range, 5–8). All HRCT and MRI studies were of diagnostic quality and were well tolerated.

Image Evaluation

All identifying information was removed from the scans. To compare chest MRI and HRCT results, we scored HRCT and MR scans, using a modified version of the scoring system developed by Helbich et al for CF.[25] The original Helbich score includes severity and extent of bronchiectasis, severity of peribronchial wall thickening, extent of mucous plugging, generation of bronchial divisions involved by bronchiectasis or plugging, extent of sacculations or abscesses, severity of bullae, severity of emphysema, severity of collapse or consolidation, and severity of mosaic perfusion.[25] We excluded the severity of mosaic perfusion from imaging evaluation because it cannot be assessed by morphologic MRI.[18] Therefore, the maximum total score was 25 points, and not 27 (Table 1). We evaluated HRCT and MRI using the modified Helbich CT score as follows: (1) for the categories "severity of bronchiectasis" and "severity of peribronchial wall thickening", we recorded the most prevalent degree of severity; (2) it was not possible to assess peribronchial wall thickening in the presence of mucous plugging; (3) hyperintensity on images had to be present for an MRI diagnosis of mucous plugging; (4) if mucous plugging was seen within the periphery of a lung segment, bronchiectasis was scored also in that segment; (5) sacculations/abscesses were defined as circular structures with a minimum diameter of 1.5 cm that were air-filled or showed an air-fluid level; (6) a size of 2 cm was required for a diagnosis of collapse/consolidation; (7) emphysema was defined as an area of decreased signal (compared with the surrounding lung parenchyma) because of a reduction of vessel and parenchymal density; and (8) in case of lobectomy or segmentectomy, the maximum scores for "severity of bronchiectasis" and "severity of collapse/consolidation" were arbitrarily assigned to the missing lobe/segments. The assessment of "extent of bronchiectasis" took into account the number of missing segments.

Six lobes were examined; the lingula was scored separately. In patients with situs viscerum inversus, the right lung was the lung in which the middle lobar bronchus and the corresponding middle lobe were identified at scans. The images were evaluated in consensus and in a blinded fashion by 2 experienced observers (1 radiologist with 8 years and 1 pediatric pulmonologist with 15 years of experience in CT interpretation). Raters were unaware of any clinical data that could have biased their interpretation of the images. MR and HRCT scans were presented to the raters in a random, independent order. HRCT scans were scored 8 weeks after the MR images, so that the HRCT findings would not influence the raters' judgments of the MRI findings.

Lung Function Assessment

Forced vital capacity (FVC), forced expiratory volume at 1 second (FEV_1), the FEV_1/FVC ratio, and forced expiratory flow at 25% to 75% of the pulmonary volume ($FEF_{25–75}$) were measured, on the same day as chest imaging, with spirometry according to American Thoracic Society.[26] A FEV_1 >85% predicted was considered normal. Patients underwent CT and MR studies in the morning and pulmonary function tests in the afternoon.

TABLE 1. Modified Helbich Scoring System for HRCT and MRI

	Score			
Category	**0**	**1**	**2**	**3**
Severity of bronchiectasis	Absent	Mild (lumen slightly greater than the diameter of adjacent blood vessel)	Moderate (lumen 2 to 3 times the diameter of the vessel)	Severe (lumen >3 times the diameter of the vessel)
Severity of peribronchial wall thickening	Absent	Mild (wall thickness equal to the diameter of adjacent vessel)	Moderate (wall thickness greater than and up to twice the diameter of adjacent vessel)	Severe (wall thickness more than twice the diameter of adjacent vessel)
Extent of bronchiectasis	Absent	1–5*	6–9*	>9*
Extent of mucous plugging	Absent	1–5*	6–9*	>9*
Extent of sacculations or abscesses	Absent	1–5*	6–9*	>9*
Generation of bronchial divisions involved (bronchiectasis or plugging)	Absent	Up to the 4th generation	Up to the 5th generation	Up to the 6th generation and distal
Severity of bullae	Absent	Unilateral (not >4)	Bilateral (not >4)	>4
Severity of emphysema	Absent	1–5*	>5*	Not applicable
Severity of collapse or consolidation	Absent	Subsegmental	Segmental or lobar	Not applicable

*Numbers of bronchopulmonary segments.

Statistical Analysis

Results are expressed as median and range values. One-way analysis of variance (ANOVA) and χ^2 test were used to compare clinical, functional, and radiologic data from the 3 groups of patients. We used Spearman rank correlation coefficient (rho) to assess correlations among the variables and agreement between HRCT and MRI scores. A coefficient of >0.8 represents good agreement. A 2-sided $P \leq 0.05$ was significant. Data were analyzed with SPSS-PC, release 13.0, SPSS Inc (Chicago, IL).

RESULTS

HRCT and MRI identified lung abnormalities in all patients. Bronchiectasis, peribronchial wall thickening, mucous plugging, and collapse/consolidation were the most frequent abnormalities both in the overall study population and in each group (Table 2). MRI failed to detect bullae in 1 patient, but identified peribronchial wall thickening and mucous plugging more frequently than HRCT. There were no other differences in the prevalences of lung abnormalities identified by the 2 techniques.

There was a good or excellent agreement between HRCT and MRI for all scores (Table 3). Figure 1 shows the excellent correlation between the total scores of HRCT and MRI (r = 0.97). We were unable to compute agreement between HRCT and MRI scores for generation of bronchial divisions involved by bronchiectasis or plugging in group A, or for extent of sacculations/abscesses and severity of bullae in group C because of the constant value attributed to these categories at HRCT and at MRI in all subjects (Table 4). Agreement between HRCT and MRI was good or excellent in each group for the remaining abnormalities. Group B patients had lower HRCT and MRI scores than patients of groups A and C for severity of bronchiectasis ($P = 0.03$ and $P = 0.047$, respectively), severity of peribronchial wall thickening ($P = 0.006$ and $P = 0.004$, respectively), generation of bronchial divisions involved by bronchiectasis or plugging ($P = 0.001$ and $P < 0.001$, respectively), and total scores ($P = 0.005$ and $P = 0.002$, respectively). Group A subjects had the highest HRCT and MRI scores for extent of bronchiectasis ($P = 0.009$ and $P = 0.01$, respectively), extent of mucous plugging ($P = 0.005$ and $P = 0.007$, respectively), and severity of collapse/consolidation ($P = 0.02$ and $P = 0.02$, respectively). No other significant intergroup differences were found.

Spirometry was performed by 34 co-operating patients (83%). FVC, FEV_1, and $FEF_{25–75}$ were 97% predicted (range, 52%–140%),

TABLE 2. Prevalences of Lung Abnormalities Identified With HRCT and MRI in the Whole Study Population and in Each Group

	Whole Study Population		Group A		Group B		Group C	
LUNG ABNORMALITY	**HRCT**	**MRI**	**HRCT**	**MRI**	**HRCT**	**MRI**	**HRCT**	**MRI**
Bronchiectasis	76%	76%	93%	93%	50%	50%	85%	85%
Peribronchial wall thickening	71%	73%	100%	100%	43%	43%	69%	77%
Mucous plugging	73%	78%	93%	100%	43%	43%	85%	92%
Sacculations or abscesses	12%	12%	7%	7%	29%	29%	0%	0%
Bullae	10%	7%	14%	14%	14%	7%	0%	0%
Emphysema	10%	10%	14%	14%	7%	7%	8%	8%
Collapse or consolidation	66%	66%	93%	93%	43%	43%	62%	62%

TABLE 3. Median HRCT and MRI Scores, and Their Agreement, in the Whole Study Population

Category	HRCT Score	MRI Score	*r*
Severity of bronchiectasis	2 (0–3)	2 (0–3)	0.96
Severity of peribronchial wall thickening	2 (0–2)	2 (0–2)	0.94
Extent of bronchiectasis	1 (0–3)	1 (0–3)	0.97
Extent of mucous plugging	1 (0–3)	1 (0–3)	0.93
Extent of sacculations or abscesses	0 (0–3)	0 (0–3)	0.89
Generation of bronchial divisions involved (bronchiectasis or plugging)	3 (0–3)	3 (0–3)	0.95
Severity of bullae	0 (0–3)	0 (0–3)	0.86
Severity of emphysema	0 (0–2)	0 (0–2)	0.89
Severity of collapse or consolidation	1 (0–2)	1 (0–2)	1
Total score	11 (1–20)	11 (1–17)	0.97

Values are expressed as median and ranges (in parentheses).

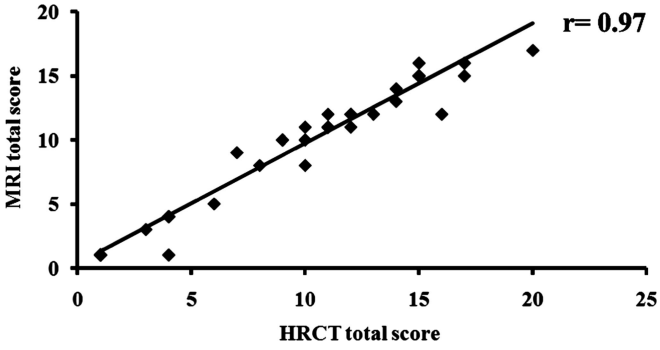

FIGURE 1. Agreement between HRCT and MRI total scores in the whole population. Twenty-three points are shown because 7 values overlap.

91% predicted (range, 28%–132%), and 71% predicted (range, 7%–129%), respectively. The FEV_1/FVC ratio was 79% (range, 45%–101%). Twenty patients (59%) had a normal FEV_1. HRCT and MRI total scores were significantly related to FVC ($r = -0.4$, $P = 0.03$; and $r = -0.4$, $P = 0.02$, respectively), FEV_1 ($r = -0.4$, $P = 0.015$; and $r = -0.4$, $P = 0.008$, respectively), the FEV_1/FVC ratio ($r = -0.4$, $P = 0.03$; and $r = -0.4$, $P = 0.02$, respectively), and $FEF_{25–75}$ ($r = -0.4$, $P = 0.02$; and $r = -0.4$, $P = 0.01$, respectively). There was a significant correlation between HRCT and MRI scores for extent of bronchiectasis and FEV_1 ($r = -0.4$, $P = 0.03$; and $r = -0.4$, $P = 0.03$, respectively), the FEV_1/FVC ratio ($r = -0.4$, $P = 0.02$; and $r = -0.4$, $P = 0.02$, respectively), and $FEF_{25–75}$ ($r = -0.4$, $P = 0.04$; and $r = -0.4$, $P = 0.03$, respectively). Unlike HRCT, the MRI mucous plugging score was significantly related to FVC ($r = -0.4$, $P = 0.03$), FEV_1 ($r = -0.4$, $P = 0.02$), the FEV_1/FVC ratio ($r = -0.4$, $P = 0.04$), and $FEF_{25–75}$ ($r = -0.4$, $P = 0.04$).

The median dose length product of the HRCT studies was 84.2 mGy × cm (range, 43.7–210.8). The median *E* was 0.76 mSv (range, 0.39–1.88). The median weighted CT dose index was 3.12 mGy (range, 2.3–5.85).

Figures 2 to 5 are examples of images obtained with HRCT and MRI. Figure 2A shows an area of consolidation in the middle lobe obtained with HRCT in a boy affected by PCD and situs viscerum inversus. The area was well visualized also with MRI (Fig. 2B). Figure 3 shows images of a large abscess in the right lower lobe obtained with HRCT (panel A) and with MRI (panel B) in a male with chronic granulomatous disease. Figure 4 shows HRCT (panel A) and MRI (panel B) images of bronchiectasis, bronchial wall thickening and mucous plugging in the left lower lobe in a male with a history of recurrent pneumonia. Figure 5A shows an HRCT image of severe bronchiectasis with partial parenchymal destruction in the middle lobe in a female with PCD. The same abnormalities were well visualized also with MRI (Fig. 5B).

DISCUSSION

In this study, we compared the efficacy of chest HRCT and high-field MRI in the assessment of the severity and extent of lung abnormalities in children and young adults with non-CF chronic lung disease. The agreement between the 2 techniques was good or excellent for all the abnormalities considered. Bronchiectasis, peribronchial wall thickening, mucous plugging, and collapse/consoli-

TABLE 4. Median HRCT and MRI Scores, and Their Agreement, in Each Group

	Group A			Group B			Group C		
Category	HRCT Score	MRI Score	*r*	HRCT Score	MRI Score	*r*	HRCT Score	MRI Score	*r*
Severity of bronchiectasis	2 (0–3)	2 (0–3)	0.86	0.5 (0–2)	0.5 (0–2)	1	2 (0–3)	2 (0–3)	1
Severity of peribronchial wall thickening	2 (1–2)	2 (1–2)	1	0 (0–2)	0 (0–2)	1	2 (0–2)	2 (0–2)	0.82
Extent of bronchiectasis	2 (0–3)	2 (0–3)	0.97	0.5 (0–3)	0 (0–3)	0.91	1 (0–3)	1 (0–3)	1
Extent of mucous plugging	2 (0–3)	2 (1–3)	0.95	0 (0–3)	0 (0–3)	1	1 (0–3)	1 (0–3)	0.84
Extent of sacculations or abscesses	0 (0–1)	0 (0–1)	1	0 (0–3)	0 (0–3)	0.85	0*	0*	NA
Generation of bronchial divisions involved (bronchiectasis or plugging)	3*	3*	NA	2 (0–3)	1 (0–3)	0.93	3 (0–3)	3 (0–3)	1
Severity of bullae	0 (0–3)	0 (0–3)	1	0 (0–3)	0 (0–3)	0.73	0*	0*	NA
Severity of emphysema	0 (0–1)	0 (0–1)	0.8	0 (0–2)	0 (0–1)	1	0 (0–2)	0 (0–2)	1
Severity of collapse or consolidation	2 (0–2)	2 (0–2)	1	0 (0–2)	0 (0–2)	1	1 (0–2)	1 (0–2)	1
Total score	12 (6–20)	12 (5–17)	0.94	4 (1–17)	3.5 (1–16)	0.92	10 (1–15)	10 (1–16)	0.97

Values in parentheses are ranges.
*Range values are not reported because all patients had the same score.
NA indicates not applicable (see text).

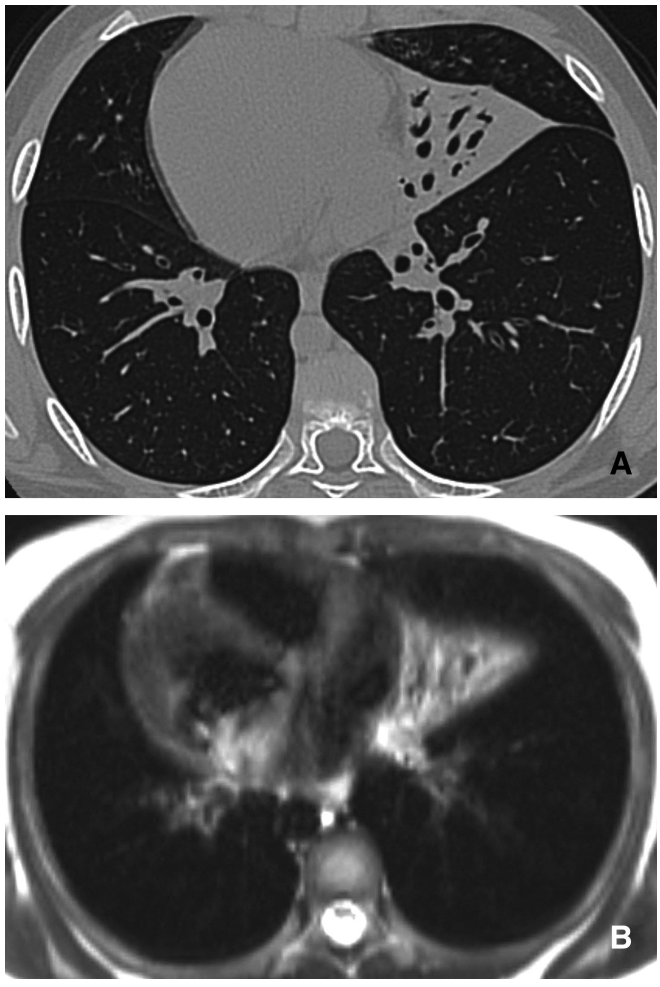

FIGURE 2. Transversal HRCT (A) and transversal MR (B) images of a 10.4-year-old boy with primary ciliary dyskinesia and situs viscerum inversus. Both scans clearly depict an area of consolidation in the middle lobe.

dation were the most frequent abnormalities. HRCT and MRI total scores, and extent of bronchiectasis scores were significantly related to PFTs. Finally, unlike HRCT, the MRI mucous plugging score was significantly related to PFTs.

The management of non-CF chronic lung disease is based on clinical assessment and sputum cultures combined with pulmonary function and lung imaging evaluation.[27,28] However, PFTs are relatively insensitive markers of early disease and fail to detect changes in the peripheral airways. Chest CT provides a more accurate picture of the type, distribution and extent of lung changes than either PFTs or chest radiography,[29] but entails exposure to ionizing radiation.[4] Therefore, there is a need for a sensitive technique that assesses lung changes without exposing patients to ionizing radiation.

Experience with lung MRI, particularly high-field MRI, is limited.[22] To determine the clinical value of chest high-field 3.0-T MRI scanning and its potential as a surrogate outcome measure in children and young adults with non-CF chronic lung disease, we compared 3.0-T MRI to HRCT, using a scoring system, ie, the modified Helbich score.[18] Although this score was devised for CF patients,[25] we used it because there is no scoring system specific for non-CF chronic lung diseases and because we found it to be easily

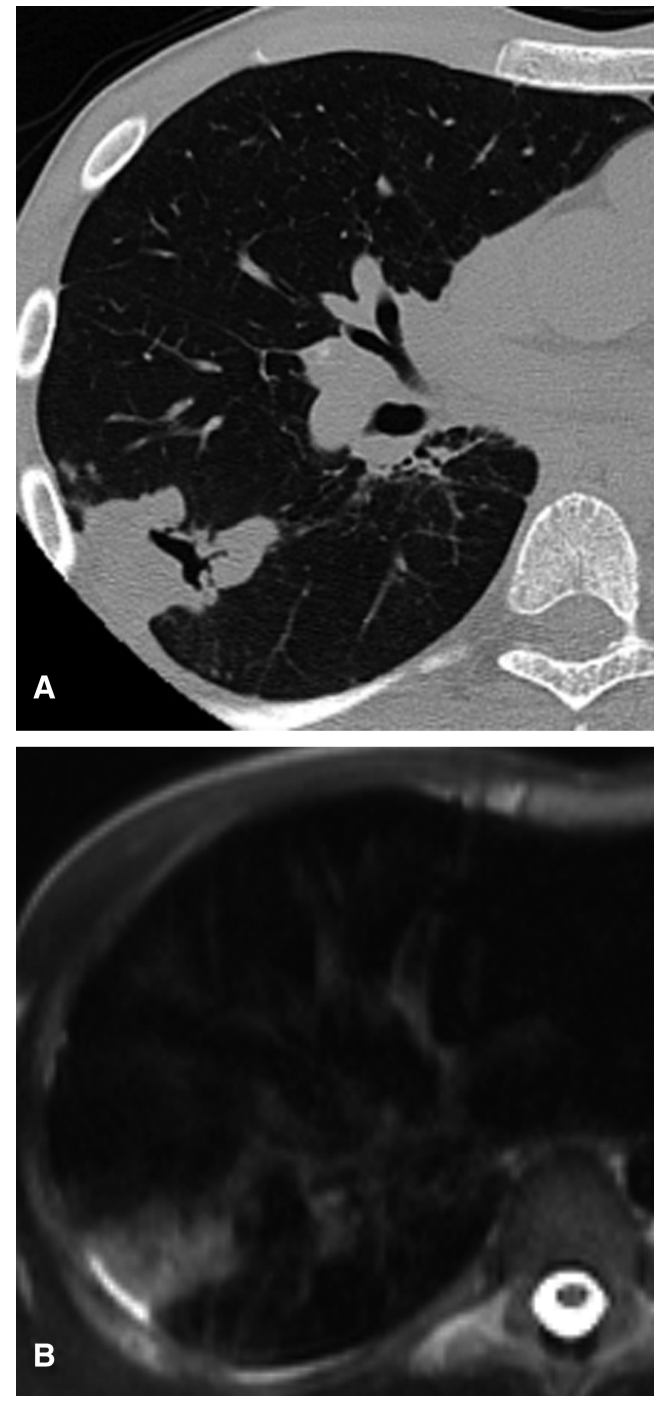

FIGURE 3. Images of a 19-year-old man with chronic granulomatous disease. A, Transversal HRCT showing a large abscess in the right lower lobe. B, Corresponding transversal MR image.

adaptable to MRI. Our data show that chest MRI findings coincide with HRCT findings, thereby supporting the concept that MRI might be an alternative, radiation-free method for pulmonary assessment in non-CF chronic lung disease as well as in CF.[17–19]

Chest MRI has several advantages over CT. First, being radiation-free it can be repeated (eg, in case of artifacts), and is thus

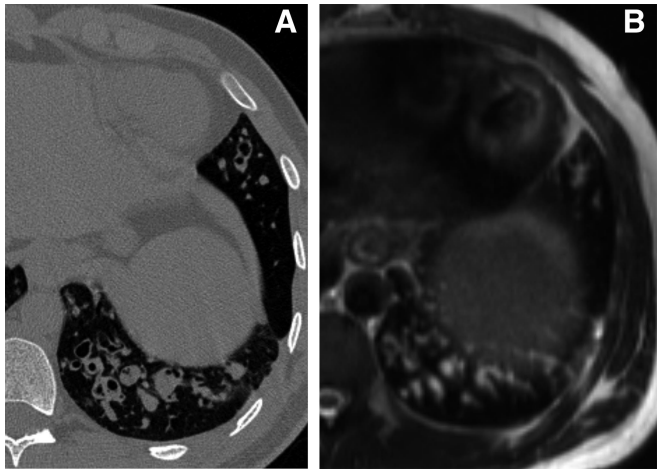

FIGURE 4. Transversal HRCT (A) and transversal MR (B) images of a 20-year-old man with history of recurrent pneumonia. HRCT and MRI show bronchiectasis, bronchial wall thickening, and mucous plugging in the left lower lobe.

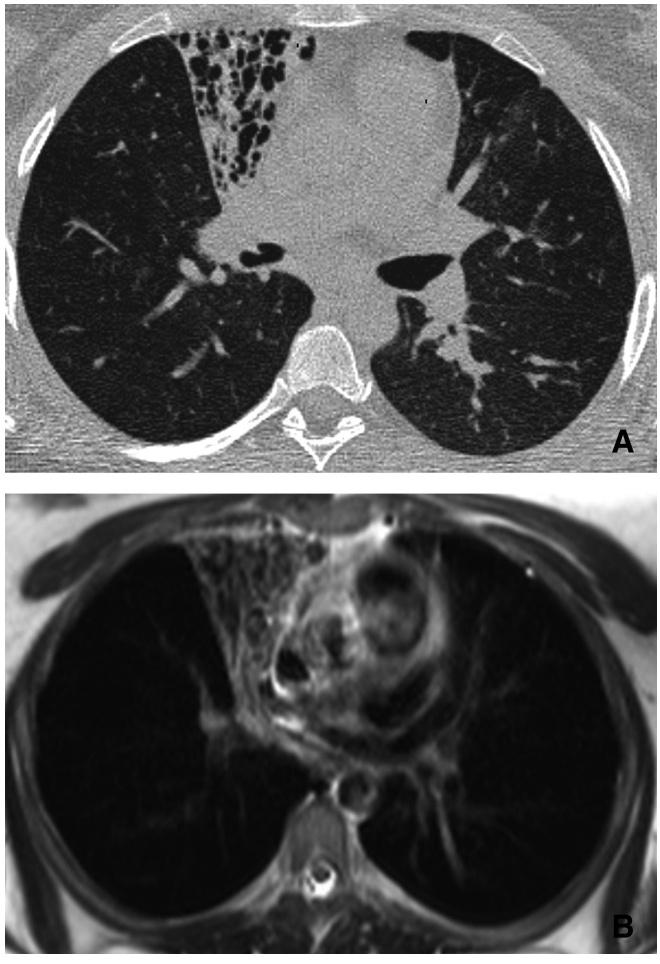

FIGURE 5. Images of a 20.9-year-old woman with primary ciliary dyskinesia. A, Transversal HRCT showing severe bronchiectasis with partial destruction in the middle lobe. B, Corresponding transversal MR image. The severe bronchiectasis and partial parenchymal destruction in the middle lobe are clearly visualized.

suitable for long-term disease monitoring. Second, MRI identifies various characteristics of lung tissue, allows a precise characterization of the lesion and assesses function, eg, lung perfusion and/or ventilation, and respiratory mechanics.[13,30] In selected patients, chest MRI may be more informative than CT. In fact, Lutterbey et al demonstrated that 3.0-T MRI of the lung performed slightly better than CT in the evaluation of disease activity in patients with interstitial lung disorders.[8] Thus, structural information and functional data are obtained in a single examination, thereby reducing imaging costs and increasing the patient's compliance.[19] Finally, unlike CT, chest MRI easily distinguishes between mucous plugging and bronchial wall thickening even in the peripheral airways.[17] This finding, probably because of the elevated proton density of mucous, is relevant because peripheral mucous plugging is a sensitive marker of early small airway disease, particularly in PCD.[31] Interestingly, we found that, unlike HRCT, the MRI mucous plugging score was significantly related to PFTs.

On the other hand, the spatial resolution of MRI is lower than that of CT, and slight morphologic changes such as peripheral bronchiectasis without bronchial wall thickening or nodules smaller than 5 mm are not consistently visualized by MRI.[17,32] Another disadvantage of MRI is that the specific absorption rate increases with field strength. However, the specific absorption rate can be decreased by using transmit/receive array coils, by reducing the number of slices, and by using parallel imaging techniques.[33] Other potential drawbacks of MRI are limited access to the technology, long acquisition times and high costs. However, we believe that the benefits of MRI outweigh the greater discomfort for the patient and the higher costs. Technical progress will hopefully lead to lower costs, shorter examination times and higher image resolution.

To our knowledge, this is the first time that 3.0-T MRI has been used for the quantitative analysis of pulmonary abnormalities in children and adults with non-CF chronic lung disorders. Although a field strength of 1.5 T is generally used in clinical practice, MR whole-body units operating at field strengths of 3.0 T and beyond are increasingly being installed in research institutions and in clinical facilities.[15,21,34] Previous studies showed that 1.5-T MRI and 3.0-T MRI have comparable image quality.[35,36] However, the overall scan time is shorter with 3.0-T MRI, at a constant image resolution, thanks to parallel imaging.[36] Moreover, a higher lesion contrast can be expected at 3.0 T.[35] On the other hand, the effects of magnetic susceptibility on T2 and on T2* increase with the field strength, and this may degrade image quality.[35] Lastly, artifacts from cardiac and respiratory motion tend to be more pronounced with 3.0-T imaging, particularly in the lower and anterior sections of the chest.[37]

The scanner we used has several advantages over 1.5-T: (1) it has a high-speed and a high-strength gradient system; (2) it is equipped with multiple phased-array coils and receiver channels; and (3) it has acquisition acceleration techniques, such as parallel imaging. Parallel acquisition techniques improve image quality by shortening the echo times of single-shot sequences.[38] Despite the high-field used, shorter echo times result in fewer blurring artifacts and less signal decay caused by T2* effects. Another advantage of the system we used is that cardiac- and respiratory-gating reduce artifacts because of heart/great vessels/chest wall motion thereby overcoming the need for sedation even in poorly cooperating subjects.

Our study has several limitations. HRCT images were acquired with the inspiratory breath-hold technique, whereas MR images were acquired with the respiratory-gating technique. However, our study population consisted mainly of children who were unable to hold their breath for a long time, despite training. In our HRCT protocol, sections were acquired during multiple inspiratory breath holds of 3 seconds each. Unfortunately, the MR HASTE sequence requires a breath hold of approximately 18 seconds.[17,18] Therefore, we

used respiratory gating to overcome the lack of cooperation in children, and applied it also to adults for the sake of uniformity.

Other limitations of our study are that HRCT scans were performed for clinical purposes, MR sequences other than HASTE were not carried out, and functional and longitudinal MRI data were not obtained. Moreover, the echo time used was not optimal. However, this did not seem to affect our findings as shown by the comparable HRCT and MRI scores. In addition, most of our patients had advanced chronic lung disease, and we did not include infants in our evaluation. Therefore, whether high-field MRI is as sensitive as HRCT, also in patients with early morphologic changes, cannot be deduced from the present study.

Finally, another drawback of our study is that images were evaluated in consensus using a modified Helbich score. This approach, also used in a previous study of CF patients,[18] was chosen by us because of scarce experience in reading morphologic MR images of chronic lung diseases in CF and non-CF patients, and because no validated MRI score is available. Therefore, our 2 evaluators had to familiarize themselves with reading the MR images and with applying the adapted scoring system we used. Clearly, a scoring system should be devised for evaluations of morphologic MR images in patients with chronic lung diseases.

In conclusion, chest high-field 3.0-T MRI appears to be as effective as HRCT in the assessment of the extent and severity of lung disease. Therefore, it might be considered a reliable radiation-free option to HRCT and be proposed for follow-up examinations.

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