Comparison between High-Resolution CT and MRI Using a Very Short Echo Time in Patients with Cystic Fibrosis with Extra Focus on Mosaic Attenuation

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Key Words

Pulmonary MRI • High-resolution CT • Cystic fibrosis • Air trapping • Pulmonary changes

Abstract

Background: It would be beneficial to establish pulmonary MRI as a complementary approach to CT for direct visualization of mosaic perfusion, bullae, and emphysema in patients with cystic fibrosis. **Objectives:** The purpose of this study was to compare both modalities, CT and MRI, using the Helbich-Bhalla score with a special focus on reliable detection of a mosaic pattern. **Methods:** Out of 51 patients examined by MRI on a 1.5-Tesla system during a period of 2 years, 19 patients were scheduled for additional low-dose CT in a clinical context. The MRI protocol comprised a gradient echo (GRE) sequence with a very short echo time (TE = 0.8 ms) in inspiration and expiration, a 3-D GRE sequence in breath hold, and a fast spin echo sequence with respiration and ECG triggering. MDCT was carried out in inspiration and adapted to body weight using 100 or 120 kV, 30–60 mA,

1- and 3-mm slice thicknesses, as well as low and high kernels. Additionally incremental slices in 3 positions were recorded in expiration for distinct detection of air trapping. CT and MRI analyses were performed by two radiologic readers in consensus unaware of the clinical parameters. The Helbich-Bhalla score of both examinations was correlated. Mean difference and accordance were assessed in each category. **Results:** There was a strong correlation between CT and MRI ($R = 0.87$, $p < 0.01$). The mean Helbich-Bhalla score for CT was 12.2 (range 1–18) and for MRI it was 11.7 (range 2–19). The mean difference was 0.5 points. Besides this strong correlation for findings (bronchiectasis, mucus plugging, peribronchial thickening, and consolidation) with a prolonged T2 TE in MRI, we could also state a qualitative agreement of 95–100% in the categories with short T2 and low signal intensity in MRI as emphysema, bullae, and mosaic perfusion. **Conclusions:** These results suggest that in our patient group none of the relevant findings were missed by MR imaging and reading.

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Introduction

Cystic fibrosis (CF) is one of the most common hereditary and congenital lung diseases and it has a great impact on the expected life span. In 85% of patients with CF, pulmonary insufficiency is responsible for early death [1]. Therapeutic interventions should cut off the vicious circle of mucostasis, bronchial instability, pulmonary infections, and tissue damage. In patients with CF the mean lifespan has been clearly prolonged by adapted therapy over the past years [2]. Potential worsening of pulmonary function is caused by a heterogeneous pattern of destruction, but none of the known genetically determined abnormalities has been reported to be solely responsible for the destruction. However, early detection of focal lung tissue damage by modern imaging modalities is important for surveillance as well as for choosing suitable therapeutic procedures.

Nowadays, CF is usually diagnosed early after birth due to the clinical appearance of neonates with predominantly salty sweat and pulmonary and digestive disorders. In the case of suspected CF it can exactly be diagnosed by DNA analysis. By far the most detected mutation on the CFTR protein (CF transmembrane conductance regulator) on chromosome 7 in Caucasians is $\Delta F508$, followed by G542X [3].

The forced expiratory volume in 1 s as a percentage of the predicted value (FEV_1 %pred) is used most frequently for assessment of the degree of severity of lung disease [4, 5]. The mean annual decrease in forced expiratory volume is approximately 2% [5].

High-resolution computed tomography (HRCT) serves as the reference standard for imaging of morphological changes of lung structure in CF and is significant in differentiation between reversible changes and irreversible destructions [6]. Air trapping (AT) as an early criterion is especially important and can be detected by expiratory CT [7]. A crucial drawback of repetitive CT examinations is, however, the high radiation exposure. Therefore, frequent CT scans (e.g. for follow-up of modified therapy schemes or additional administration of corticosteroids) especially in infants and schoolchildren are not recommended.

Due to technical development of MRI, recent studies have shown the potential of this modality for surveillance of CF patients with no radiation exposure [8–11]. On the other hand, most routine MRI techniques cannot visualize lung parenchyma. Compared to HRCT, tissues of low density and fast transverse relaxation are the major limitation of MRI. However, reliable detection of fo-

cal areas of low density (i.e. mosaic patterns as visualized by CT) is important for adequate assessment of the status of lung tissue in CF. Unfortunately, lung tissues of normal and reduced density show very rapid signal decay in MRI, mainly caused by susceptibility effects. Moreover, this effect is proportional to the static magnetic field strength (i.e. $T2^*$ values of lung are approximately 8–16 ms at 0.2 T and only 1–1.5 ms at 1.5 T) [12]. In order to overcome this limitation, a gradient echo (GRE) sequence with a very short echo time ($TE < 1$ ms) was implemented for pulmonary imaging in our clinic as described by Hatabu et al. [13]. Using this sequence, an improved quantitative and qualitative analysis of normal and reduced lung proton density was reported to be feasible.

Different radiological scoring systems have been developed for the assessment of pulmonary findings in CF. For CT the Helbich-Bhalla score has shown reasonable inter- and intraobserver variability. Furthermore, the score correlated significantly with the pulmonary function test (PFT) [6, 14, 15]. In a former study by Puderbach et al. [8], this CT score was adapted to proton MRI. Thereby, the finding ‘mosaic attenuation’ as proposed by Helbich has not been assessed due to insufficient visualization of lung tissue by the MRI techniques applied.

In contrast to recent studies, we implemented a very short echo MRI technique for improved visualization of lung tissue with low proton density. Using this relatively new approach, we analyzed the potential of MRI regarding the possible detection of typical findings in CF patients. A special focus was set on MRI appearance of typical mosaic attenuation signs in CT scans. The original Helbich-Bhalla score was used for analysis of findings in CT and MRI.

Material und Methods

Patients

During a period of 2 years, 51 patients with CF (29 females, 22 males) aged 7–39 years with a mean age of 14 years (SD 6 years) were scheduled for pulmonary MRI. The clinical trial was approved by the local Ethics Committee of our university clinic. All patients (or their guardians for patients younger than 18 years) gave informed consent. The mean FEV_1 %pred of these 51 patients was 79% (SD 22%, range 27–118%). A subgroup of 19 patients (11 females and 8 males) aged 8–29 years with a mean age of 15 years (SD 5 years) was scheduled for a low-dose CT within the same time frame. The clinical indications for CT examination were a decrease in the forced expiratory volume (FEV_1 %pred) $> 3\%$ per annum, acute exacerbation, or first admission to the clinic. The mean period between CT and MRI was 4 days (range 0–19 days,

median 0 days). In all patients, a PFT using whole body plethysmography (Masterlab-Body; Jaeger, Wuerzburg, Germany) was performed. The mean FEV₁ %pred was 74% (SD 21%, range 43–110%) (table 1).

MRI

All examinations were performed on a 1.5-Tesla device (Magnetom Vision Sonata; Siemens Medical Systems, Germany) with a maximal gradient strength of 40 mT/m and a slew rate of 200 mT/m/ms. For all studies, a 6-channel body array coil supporting parallel imaging technique was used.

A 2-D GRE sequence with a very short ET was applied in inspiration and expiration with patients in the supine position. Four series of sagittal images (each set with 4–6 slices) were recorded on the left lung and on the right lung. Technical parameters: TR, 2.5 ms; TE, 0.8 ms; flip angle, 5°; band width, 956 Hz/Px; effective pixel size, 2.0 × 1.6 mm; slice thickness, 15 mm, 6 averages, and acquisition time, 8 s. Examination procedures were carried out by a technician who is particularly experienced in pediatric radiology. After positioning, the patients were asked to breathe in and out as deeply as possible and hold their breath. The accuracy of the breath hold maneuvers was monitored online by a respiration belt which was placed prior to examination in the region of maximal excursion. For windowing, we matched the center individually above the basal noise level and the window approximately two times higher than the center. This procedure leads to an image impression in MRI similar to CT using the standard lung window.

For morphological image analysis, a 3-D GRE sequence was applied with transverse slab orientation. The parameters were: TR, 2.84 ms; TE, 0.87 ms; flip angle, 5°; effective pixel size, 1.7 × 1.4 mm; slice thickness, 3 mm, and 3 overlapping blocks with 40 slices each. Measurements were performed in inspiration with a breath hold period of 12 s for each block. Analysis of MR images was performed using original recorded slices and thin sliding maximum intensity projection (MIP) after interpolation in slice direction.

Furthermore, we implemented a T2 fast spin echo (FSE) sequence in coronal orientation with the following parameters: TR, 4,000 ms; TE, 97 ms; flip angle, 150°; effective pixel size, 1.6 × 1.6 mm; slice thickness, 6 mm, and parallel imaging (Grappa 2). These measurements were assisted by cardiac and respiratory triggering during diastole and expiration. The acquisition time was 5–10 min, dependent on the cardiac and respiratory frequency.

Computed Tomography

The CT examination was performed on a 40-slice multidetector computed tomograph (MDCT; Sensation Open; Siemens, Forchheim, Germany). Scan parameters depended on the body weight (80–120 kV and 30–60 mA). MDCT of the thorax was carried out in inspiration. Additionally, an incremental expiratory CT scan in 3 positions (upper, middle, and lower thorax) was performed. Slices of 1- and 3-mm thickness (increment 10 mm) were reconstructed with a hard and low kernel (B30 and B60) and imaged in a lung and mediastinal window.

Image Analysis

Image analysis was performed by two radiologists in consensus without having prior information regarding the clinical pul-

Table 1. Patients' data

Patient No.	Gender	Age years	FEV ₁ %pred	Microbial flora
1	F	11	51	SA, AF, CL
2	F	16	45	SA, PA, CA, AF
3	M	29	67	SA, CA
4	F	24	43	PA, AF
5	F	16	85	SA, SM, AF
6	F	8	54	SA, PA
7	M	16	68	SA, PA, AF
8	M	17	91	SA
9	M	14	45	SA, AF, CP, AT
10	F	9	69	SA, AX, CA
11	M	9	59	SA
12	M	12	110	–
13	F	9	73	SA, AX, CA
14	M	10	86	SA, PA, HI
15	F	16	107	SA, SM
16	F	21	68	AF, CA, AFI
17	F	15	74	PA, CA
18	F	14	69	SA, PA, CI
19	M	17	91	SA

As a clinical issue microbial flora at the same time of MRI and CT scan: SA = *Staphylococcus aureus*; PA = *Pseudomonas aeruginosa*; CA = *Candida albicans*; AF = *Aspergillus fumigatus*; CL = *Candida lusitanae*; SM = *Stenotrophomonas maltophilia*; CP = *Candida parapsilosis*; AT = *Aspergillus terreus*; AX = *Alcaligenes xylosoxidans*; HI = *Haemophilus influenzae*; AFI = *Aspergillus flavus*; CI = *Chryseobacterium indologenes*.

monary condition. Primarily CT images were analyzed. In order to avoid a recall bias, the MR image analysis was performed 4 weeks later by the same radiologists. For both analyses, the Hellich-Bhalla score was used as described in the literature and defined for the particular categories [6, 14] (table 2).

Mosaic attenuation was analyzed for both respiratory phases. Mosaic-like reduced attenuation in CT might result from different pathogeneses; patchy interstitial diseases, occlusive vascular diseases, or obliterative small airway disease are known as possible reasons for this phenomenon. As a mosaic attenuation pattern subsumes various different kinds of pulmonary changes, a reliable assessment of AT in CF by single CT or MRI scans remains challenging. Comparison of CT and/or MR images recorded in inspiration and expiration seems to be an appropriate means for identifying lung areas without gas exchange. In our examinations image pairs recorded in inspiration and expiration were recorded using both modalities (CT and MRI). Thus, we could differentiate between AT and other causes of a mosaic attenuation pattern [7]. In CT lack of an increase in attenuation in expiration indicates AT [6, 16]. In MRI we applied the following definition for AT: low or not identifiable signal above base noise level in inspiration with a missing gain in mosaic-like signal intensity in expiration (fig. 1, 2).

Fig. 1. Visualization of AT in a 10-year-old girl. **a** Inspiratory CT in sagittal reformation for a better side-to-side demonstration (not implemented in our CT study protocol). A clear mosaic pattern with zones of lower attenuation (arrows) is demonstrated. **b** PDw 2-D sequence in sagittal reformation (TE = 0.8 ms). Identical spreading of the mosaic pattern is seen.

Table 2. The original Helbich-Bhalla score for the evaluation of pulmonary findings in CF that we used for both CT and MRI

Category	Score			
	0	1	2	3
Bronchiectasis	absent	mild (slightly greater than the adjacent blood vessel)	moderate (2–3 times the adjacent blood vessel)	severe (>3 times the adjacent blood vessel)
Peribronchial thickening	absent	mild (equal to the adjacent blood vessel)	moderate (1–2 times the adjacent blood vessel)	severe (>2 times the adjacent blood vessel)
Bronchiectasis ¹	absent	1–5	6–9	>9
Mucus plugging ¹	absent	1–5	6–9	>9
Sacculations/abscesses ¹	absent	1–5	6–9	>9
Generation of bronchial divisions ²	absent	up to 4th generation	up to 5th generation	up to 6th generation
Bullae	absent	unilateral <4	bilateral <4	>5
Emphysema	absent	1–5	>5	
Mosaic perfusion	absent	1–5	>5	
Consolidations/collapse	absent	subsegmental	segmental/lobar	

¹ Number of bronchopulmonary segments. ² Bronchiectasis or mucus plugging.

Statistical analysis was performed using SAS jmp® (SAS Institute, Cary, N.C., USA). The score values derived from CT and MRI data were normally distributed (the p value of the Shapiro-Wilk test was larger than 0.05). Thus, we used a two-tailed t test for analysis of variance. The arithmetic mean and SD of the scores of both methods were calculated. Pearson's correlation served for assessment of the positive correlation of the interval scaled and dichotomy values of the Helbich-Bhalla score. $p < 0.05$ was considered statistically significant. We calculated the mean difference between CT and MRI scores and its SD. On an individual patient scale, deviations (nominal and percentage) of MRI and CT findings in each category were determined. Furthermore, we compared the scores of CT and MRI with the forced expiratory volume (FEV₁ %pred) according to Pearson.

Results

In our study, 18 of 19 patients presented with bronchiectasis and peribronchial thickening that was detected in MRI, and 17 of 19 patients showed mucus plugging (fig. 3, 4). In all patients signs of a mosaic pattern (as revealed by CT) were detected by MRI as well. Less frequently we found emphysema, abscesses, consolidations (fig. 5), and bullae (fig. 6) (1, 2, 11, and 2 of 19 patients, respectively) by MRI.

The mean value of the CT score was 12.2 (range 1–18, SD 4.07) and for MRI it was 11.7 (range 2–19, SD 3.96) (a maximum of 27 points could be achieved). The mean dif-

Fig. 2. Transversal CT (**a, b**) and sagittal PDw 2-D MRI (**c, d**) of a 16-year-old girl. Acquisition in expiration (**a, c**) and inspiration (**b, d**). Subsegmental areas of mosaic pattern (arrows) are visualized more clearly in expiratory scans particularly in MRI.

ference was 0.5 points (SD 2 points). There was a relatively strong correlation between both methods, with $R = 0.87$ and $p < 0.01$ (fig. 7). Assuming unequal variance, there was no significant difference between CT and MRI scores (standard error 1.3 points; $p = 0.72$, $p = 0.64$, and $p = 0.36$ for two-tailed, lower-tailed, and upper-tailed tests, respectively).

The individual agreement of the score values was analyzed and the derived results are summarized in table 3. In 76% of the patients, the score values of all listed categories (bronchiectasis, peribronchial thickening, mucus plugging, sacculations/abscesses, bullae, emphysema, mosaic perfusion, and consolidation pattern) were identical for CT and MRI. A difference of 1 point appeared in 22% of the subjects, with an underestimation by MRI in 14% and an overestimation by MRI in 8% of the subjects. A deviation of more than 1 point was shown in only 2% of the patients. Thus, the overall agreement between both modalities was excellent.

The scores in CT and MRI, respectively, showed a clear negative linear correlation to the FEV_1 %pred ($R = -0.79$ and -0.78 ; $p < 0.01$), according to the results of de Jong et al. [15] (fig. 8).

Discussion

Numerous studies have shown the high performance of MRI in comparison to CT or to chest X-ray as the reference standard for diagnosis and for the extent of pulmonary changes in CF [13, 15, 17]. In the study presented here, we analyzed typical pulmonary findings of the disease in both CT and MRI with special focus on mosaic patterns as a surrogate of focal AT. Using the widespread Helbich-Bhalla score, we obtained a strong correlation between both methods ($R = 0.87$). A recent study also compared CT and MRI with modification of this score by excluding the category mosaic pattern [8, 9], which

cannot be visualized by standard pulmonary MRI [i.e. T2-weighted spin echo or volumetric interpolated breath hold sequence (VIBE) sequences] as mentioned above. Implementing a GRE sequence with a very short ET, as described for imaging of lung tissue by Hatabu et al. [13] in 2000, we could overcome former limitations of pulmonary MRI. In brief, shortening the ET is possible by using extremely short and asymmetric pulses, relatively high slice thicknesses, and a high receiver bandwidth [18].

AT, Emphysema, and Bullae

Obliterating bronchiolitis with consecutive focal AT is one of the earliest pulmonary manifestations in CF patients who could have normal PFT. In addition, the detection of AT seems to be an important issue for surveillance and treatment control [19]. Focal AT is defined by areas of low attenuation in the expiratory CT. The CT scan is usually carried out with a large gap (i.e. 20 mm) between slices or in distinct regions of the thorax as performed in our routine protocol and is combined with a volume scan in inspiration. Although it would be theoretically favorable to cover both phases by volume CT, this procedure is obsolete particularly for young patients due to doubling of radiation exposure [20].

In contrast to CT, MRI allows coverage of the whole lung in real time during respiration using timely resolved 3-D techniques [21]. Unfortunately, the signal-to-noise

3

Fig. 3. Bronchiectasis and mucus plugging in the right upper lobe in a 16-year-old boy that represent the typical morphological findings in patients suffering from CF. **a** Transversal CT. **b** Transversal 3-D GRE sequence (thin MIP). **c** Coronal 2-D T2w FSE. The findings in transversal MRI were comparable to those in CT. The coronal T2 FSE sequence also shows these findings impressively.

Fig. 4. Marked peribronchial thickening in the right upper lobe of a 16-year-old girl as well as clear mucus plugging in peripheral zones (tree-in-bud sign). Transversal CT (**a**) and thin MIP (**b**). Transversal 3-D GRE sequence as thin MIP (**c**) and coronal 2-D T2w FSE (**d**). In transversal and coronal MRI similar findings are detectable. Especially the tree-in-bud sign is well demonstrated, indicating small airway disease.

4

Fig. 5. Clearly depicted paracardial consolidations on both sides (arrows) in a 16-year-old girl showing nonventilated lung parenchyma with reduced lung volume capacity. **a** Transversal CT. **b** Transversal 3-D GRE sequence. **c** Coronal 2-D T2w FSE. Comparable visualization of consolidations in CT and MRI. Due to short 3-D acquisition time and triggering, respectively, there was no phase artifact at the border of the heart.

Fig. 6. Large septated bulla in the left upper lobe (arrows) in a 24-year-old female patient. **a** Transversal CT. **b** Transversal 3-D GRE sequence. **c** Coronal 2-D T2w FSE. In MRI this large bulla could be visualized in all sequences.

Table 3. Score of MRI compared to CT and deviation of the point score +1/-1/>1

Category	Patients with the same point score, n	Deviation of point score		
		-1	+1	>1
Bronchiectasis	12 (63%)	4	2	1 ¹
Peribronchial thickening	17 (89%)	1	1	0
Bronchiectasis, concerned segments	13 (68%)	5	1	0
Mucus plugging	12 (63%)	4	3	0
Sacculations/abscesses	15 (79%)	3	1	0
Mucus plugging, bronchial divisions	14 (74%)	1	1	3 ²
Bullae	18 (95%)	1	0	0
Emphysema	19 (100%)	0	0	0
Mosaic perfusion	11 (58%)	4	4	0
Consolidation	13 (68%)	3	3	0
Mean	14.4 (76%)	2.6 (14%)	1.6 (8%)	0.4 (2%)

Point score +1/-1/>1 deviation. With a deviation of ± 1 point there was an agreement between both modalities of 98%. ¹ -2 points in 1 patient. ² In 1 patient +3, -2, and -3, respectively.

Fig. 7. Correlation of the sum values of the original Helbich-Bhalla scores for CT and MRI. The diagram shows that the point values of the MRI evaluation are strongly correlated to the reference point values of the CT evaluation.

Fig. 8. The correlation of the sum values of the Helbich-Bhalla scores for CT (triangles)/MRI (asterisks) with the functional FEV₁ value (% of predicted value) of the lung function test shows a strong linear tendency to morphological MRI and CT findings to the functional pulmonary presentation of our patients.

ratio of normal lung parenchyma is too low for differentiating normal tissue areas from areas with trapped air. Due to the fact that detection of areas with a low proton density (i.e. emphysema or AT) is very challenging, several research groups have conducted functional studies using oxygen-enhanced or hyperpolarized 3-helium imaging. Regardless of the promising results, most of these methods have not been widely accepted because they are relatively complicated. In our eyes a more simple approach can be used by adding a sequence with a very short TE to common MR protocols. The advantage of this approach is its capability to provide sufficient signal intensity from normally and pathologically altered lung tissue in acceptable breath holds with a duration of 8 s for each lung side and respiratory phase.

In this study an additional expiratory CT volume scan would be ideal for a side-by-side evaluation. Due to ethical aspects this scan was not available. Thus, a separate reading of CT and MRI seemed to be appropriate for estimation of MRI performance for AT. However, in some cases, as shown in figure 1, AT can also be seen on inspiratory images if CT window and center settings are narrowed. In this example, an excellent visual correlation is shown. Using relatively thick slices of 15 mm in MRI in a sagittal orientation, assessment of the same parts of the lung in both phases was feasible. Findings such as mucus plugging or consolidations appeared bright in inspiration

and expiration, whereas focal AT appeared dark in both images. Distinct changes of signal intensity indicate normally ventilated lung areas (fig. 2).

AT was found in 19 of 19 patients in MRI and in 18 of 19 patients in expiratory CT. The same CT and MRI score values for AT were found in 11 of 19 patients, and over- and underestimation of 1 point by MRI score compared to CT was found in 8 patients. No patient with marked AT as indicated by CT (n = 13) was rated negative by MRI. There are some reasons for the relatively weak correlation. A different orientation (MRI in sagittal vs. CT in transverse orientation) and volume coverage might provoke an underestimation of the detected affected segments by expiratory CT (in expiration only 3 slice positions were scanned). Furthermore, there are basic physical restrictions in MRI that could lead to limited sensitivity to pathological changes. Assuming that the T2* ET of normal lung tissue is less than 0.6–0.8 s in inspiration and about 1.1–1.4 s in expiration, further shortening of the ET to values shorter than 0.8 s would be beneficial at 1.5 T [12].

Generally, there are major limitations in MRI for visualization of emphysema and bullae [22]; however, we could detect these changes due to the short ET that we applied. Areas of the lungs that were nearly free of signal (comparable to ambient air) were demarcated in MRI compared to normal lung tissue. Bullae could especially

be detected by morphological characteristics such as an oval shape and, for example, septum. As a limitation we have to note that these changes occurred rarely in our patients and so a selection bias might be apparent.

Bronchiectasis, Peribronchial Thickening, Mucus Plugging, and Consolidations

As depicted in several studies, MRI is a useful tool for visualization of inflammatory changes [19, 23]. In agreement with these established data, we found a strong correlation in the assessment of peribronchial thickening (17/19). Especially T2-weighted images acquired in a coronal orientation showed a high spatial resolution (pixel size $1.6 \times 1.6 \text{ mm}^2$) of central and intermediate bronchial tubes. This high image quality with very few motion artifacts excuses the expenses of an acquisition time of 5–10 min for this particular sequence. Especially if there is no inflammatory bronchial wall thickening, there might be an underestimation of the extent of bronchiectasis as detected in 5 patients. Whereas in 4 patients a deviation of 1 point was detected, there was 1 patient (8 years) with an underestimation of 2 points. The clinical importance of these methodical limitations in MRI might be relatively low since de Jong et al. [15] did not find a high correlation between an increase in peripheral bronchiectasis and loss of FEV_1 %pred [15].

Another CT study, however, showed a strong correlation between the extent of bronchial wall thickening, the tree-in-bud sign, mucus plugging, and the forced expiratory volume [24]. Segmental mapping in MRI was feasible. The assessment of concerned bronchial divisions differed in 4 of 19 patients. Under- and overestimation of findings more peripheral than the 6th generation or more central than the 5th generation of bronchial divisions did not differ significantly. Reasons for under- and overestimation, respectively, are generally due the spatial resolution and increased susceptibility of discrete centrilobular changes less than 1 mm in size. Surprisingly, a partially different assessment of consolidations (maximum 1 point) concerning their size might predominantly be the result of the period between both examinations in a few cases and, therefore, evidence of some variability in the extent of atelectasis.

Clinical Aspects

Pulmonary MRI was performed in multiple orientations in a relatively short acquisition time with acceptable breath holds of approximately 8–9 s maximum. Even the youngest patients (minimum 8 years) normally had no problem following the breathing instructions. This cer-

tainly was also a benefit of the familiarity of these patients with forced breath holds. We examined even younger patients by MRI, but there was no indication for a CT for clinical reasons at the same time. Nowadays, an MRI examination normally takes more time than a CT examination. However, considering repeated and multiple follow-up examinations, an MRI examination without contrast media application and with a duration of 20 min seems to be acceptable. Due to the radiation exposure of regular follow-up examinations, CT scans should be avoided [20]. The clinical relevance of a general pulmonary MRI screening of CF patients with normal lung function was not part of this study, but we expect a high acceptance of this method among physicians and patients. Previous studies have compared CT changes with clinical parameters repeatedly [2, 4]. CT offers a solid and improved diagnostic value as a screening modality to detect changes in lung structure [17, 18] and is superior to a sole follow-up of clinical parameters of the lung.

Both modalities well determined the severity of this disease, and so we could confirm a strong correlation between the point score and the forced expiratory volume, as already shown in other studies in a similar mode [16, 23].

Beyond advantages of MRI for longitudinal studies in CF with lack of radiation exposure, MRI could facilitate treatment control in a shorter follow-up. Moreover, a strong correlation between CT and MRI was found for peribronchial thickening and peripheral mucus plugging. Therefore, current high-dose anti-inflammatory concepts could be a target for MRI considering adverse effects and unknown mechanisms of NSAD like ibuprofen [25].

Limitations

With regard to selection bias, the most frequent changes in our patients were bronchiectasis, peribronchial thickening, mosaic perfusion, and mucus plugging. Especially the severity and extent of these changes were important. In most cases the CT scan was performed with an advanced clinical indication (acute exacerbation, infection, and loss of FEV_1 %pred), so there might have been a more extended appearance of pulmonary changes in these patients. This might have led to better agreement of our results. However, considering a strong correlation between cross-sectional imaging and clinical parameters (PFT and FEV_1 %pred), we can generally assume that we have a reliable predictive value.

Another limitation is the performance of consensus image reading. Interobserver agreement was not ana-

lyzed due to our prior aim to see if we could basically detect and properly assess typical CF changes of the lung especially including AT in MRI. In accordance with other studies using similar scoring systems, we can advert to a high intra- and interobserver agreement [26].

In three patients, CT and MRI were not performed on the same day (range 0–19 days, median 0 days), resulting in a possible discrepancy in both methods. In 2 patients the period between MRI and CT was 1 day. In 1 patient the period between MRI and CT was 19 days due to a prior admission to the CF outpatient clinic with performance of the MRI examination. Clinical parameters basically did not change in this period.

Conclusion

In pulmonary MRI, all clinically relevant changes of the lung could be detected compared to HRCT. There was a strong correlation between MRI and CT in most categories and a strong correlation in the overall assessment using the Helbich-Bhalla score. With a 1-point difference in score values between both modalities there was a 98% agreement. Due to this fact, we conclude that MRI is a robust modality comparable to CT in assessing patients suffering from CF using our scan protocol. The beneficial absence of radiation exposure should not be neglected regarding frequent follow-up examinations and an increasing life span of CF patients.

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