European Journal of Radiology 111 (2019) 88–92

Contents lists available at ScienceDirect

European Journal of Radiology

journal homepage: www.elsevier.com/locate/ejrad

Research article

Evaluation of 3 T lung magnetic resonance imaging in children with allergic bronchopulmonary aspergillosis: Pilot study

Kushaljit Singh Sodhi[a,*], Pankaj Gupta[a], Amit Shrivastav[a], Akshay Kumar Saxena[a], Joseph L. Mathew[b], Meenu Singh[b], Ritesh Agarwal[c]

[a] Department of Radiodiagnosis and Imaging, PGIMER, Chandigarh, India
[b] Department of Paediatrics, PGIMER, Chandigarh, India
[c] Department of Pulmonary Medicine, PGIMER, Chandigarh, India

ARTICLE INFO

Keywords:
MRI
CT
Chest
ABPA
Imaging
Pediatrics

ABSTRACT

Objective: To evaluate the diagnostic performance of 3 T lung magnetic resonance imaging (MRI) in children with allergic bronchopulmonary aspergillosis (ABPA).

Materials and methods: This study protocol was approved by the institutional ethics committee. From October 2015 to January 2018, we prospectively evaluated twenty-seven consecutive children with ABPA. The diagnosis of ABPA was made on the ISHAM-ABPA working group criteria. High resolution computed tomography (HRCT) and 3 T MRI of the chest was performed on the same day. Bronchiectasis, consolidation, nodules, and mucus impaction were assessed in all segments. The sensitivity, specificity, positive predictive value (PPV) and negative predictive value (NPV) of MRI were calculated using HRCT findings as the reference standard. Interobserver agreement was calculated using the kappa statistic.

Results: The mean age of the patients was 9.89 years (range: 5–16 years). There were 20 males and 7 females. The sensitivity, specificity, PPV, and NPV for bronchiectasis was 68%, 100%, 100% and 71.43% respectively. The sensitivity, specificity, PPV, and NPV for consolidation was 80%, 100%, 100% and 96% respectively. For detection of nodules, the sensitivity, specificity, PPV, and NPV was 75%, 100%, 100% and 88.46% respectively. There was 100% sensitivity, specificity, PPV and NPV for mucus impaction. There was a high degree of inter-observer agreement for MRI findings (k = 0.9–1) as well as agreement (k = 0.7–1) between CT and MRI for all the four findings.

Conclusion: With the currently available routine MR sequences, MRI demonstrates high specificity but less sensitivity and negative predictive value to HRCT scan in children with ABPA. Newer MR sequences need to be explored and validated to enhance the potential of lung MRI in ABPA.

1. Introduction

While the diagnosis of ABPA is primarily made on the basis of immunological tests (*A. fumigatus* IgE, total IgE, *A. fumigatus* IgG, total eosinophil count), imaging is often required in patients with ABPA. Imaging identifies the 'end-organ' damage caused by the disorder and makes a case for treating a patient, irrespective of the presence or absence of symptoms. Patients with ABPA without any radiological abnormality due to the disease are classified as serological ABPA. These patients are generally treated only with inhaled steroids, while those with bronchiectasis require oral glucocorticoids [1]. Chest radiographs are inferior to computed tomography (CT) in the detection of bronchiectasis [2]. Overall, radiographs have a poor sensitivity and specificity for the diagnosis of ABPA [2]. HRCT chest is the accepted imaging modality for evaluation in patients suspected to have ABPA [3]. However, CT entails exposure to ionizing radiations. This is of concern particularly in children] as reports of a possible risk of cancer attributed to radiation exposure [4,5]. An alternative imaging modality with no risk of radiation hazard and a high diagnostic performance is desirable. Magnetic resonance imaging (MRI) has not been traditionally employed for lung evaluation due to low proton density of lungs and high propensity for artifacts [6]. However, major technological advancements have made this application of MRI now feasible. Promising results have been reported in several conditions with lung MRI [7–11].

* Corresponding author at: Department of Radio Diagnosis and Imaging, Post Graduate Institute of Medical Education and Research, Sector-12, Chandigarh, 160012, India.
E-mail address: sodhiks@gmail.com (K.S. Sodhi).

https://doi.org/10.1016/j.ejrad.2018.12.021
Received 24 September 2018; Received in revised form 24 December 2018; Accepted 28 December 2018

However, to the best of our knowledge, there are no studies on the use of 3-tesla lung MRI in children with ABPA. The present study was conducted to evaluate the diagnostic performance of lung MRI in children with ABPA.

2. Material and methods

This study protocol was approved by the institutional ethics committee and written informed consent was obtained from the parents/guardians of all children enrolled in the study. Confidentiality of all patients was maintained using the principles of the Health Insurance Portability and Accountability Act (HIPAA) guidelines.

2.1. Study population

From October 2015 to January 2018, we prospectively included 27 consecutive pediatric patients (aged 5–16 years), referred for the radiological evaluation of allergic bronchopulmonary aspergillosis (ABPA). The diagnosis of ABPA was based on multidisciplinary evaluation by a team comprising of pediatricians, pulmonologists, physicians, immunologists, pathologists, and mycologists. ABPA was diagnosed on the basis of ISHAM-ABPA working group criteria (Table 1) [12]. MRI was performed after HRCT chest in all patients on the same day.

2.2. Imaging technique

2.2.1. CT protocol

HRCT of the chest was performed on a 64-row multidetector CT scanner (Aquilion64; Toshiba America Medical Systems, Otawara, Japan). The scans were acquired from the lung apex to the base. Scan parameters were 120 kVp, 100–150 mA, 1-mm collimation, and a high-spatial resolution image reconstruction algorithm was used. Axial CT images were later reconstructed using soft tissue reconstruction algorithms. The images were reviewed on a TeraRecon workstation (Foster City, CA) at standard lung window (level: 500 HU, width: 1500 HU) and mediastinal window (level: 350 HU, width: 50 HU) settings.

2.2.2. MRI protocol

MRI of the chest was performed on a 3 T MRI scanner (Ingenia; Philips Health Systems, Amsterdam, The Netherlands). All MRI sequences were acquired with a breath-hold protocol. Prior to MR acquisition, breath-hold was explained to all the patients and parents. Children who were uncooperative, dyspnoeic or unable to hold breath were not included. No respiratory and electrocardiogram gating was performed. No sedation or contrast was administered.

MRI scans were obtained in the axial plane in the craniocaudal direction in all children. The following MRI pulse sequences and parameters were employed: (1) T2-weighted turbo spin echo (repetition time [TR] 1250 ms, echo time [TE] 80 ms, slice 4 mm, flip angle 90°, field of view [FOV] 300 mm, matrix 216 × 189); (2) Dixon T1 (TR 2.6 ms, TE 1.32 ms, slice 4 mm, flip angle 90°, FOV 250 mm; matrix 156 × 124); (3) balanced turbo field echo (TR 2.6 ms, TE 1.32 ms, slice 4 mm, flip angle of 45°, FOV 270 mm, matrix 152 × 135); and (4) Multivane MVTX (TR 2500 ms, TE 127 ms, slice 4 mm, flip angle 90°, FOV 275 mm, matrix 184 × 184). Multivane is a PROPELLER (Periodically Rotated Overlapping Parallel Lines with Enhanced Reconstruction) sequence (Philips, Netherlands). The total scan time was approximately 7 min. The total MR table time varied from 15 to 20 min.

Table 2
Radiological findings in 27 children with ABPA on CT and MRI.

Findings	CT (Number of involved lobes)	MRI (Number of involved lobes)
Bronchiectasis	25	17
Consolidation	5	4
Nodules	12	9
Mucus impaction	2	2

2.2.3. HRCT and MR image evaluation

HRCT and MR images were reviewed by two radiologists, with 12 years and 6 years of experience in thoracic CT and MRI interpretation. Both the radiologists were blinded to the clinical profile of the children. In addition, all the images were anonymized. The order of HRCT and MR images was randomized. These scans were evaluated over two different reading sessions, with periods of 1 week between two sessions. The quality of MRI and HRCT images were initially classified into three categories: 0 (not diagnostically acceptable), 1 (few artifacts, but images are diagnostically acceptable), and 2 (good diagnostic images without substantial artifacts). MRI and CT studies with diagnostic quality (category 1 or 2) were reviewed. The findings that were assessed included: consolidation, nodules, bronchiectasis and mucoid impaction. Above analysis was performed in each patient on per-lobe basis (total of 5 lobes in each patient) on both CT and MRI. If mucoid impaction was present, its density (on HRCT-mediastinal window)/signal intensity (on MRI) was evaluated. If the density was more than that of the paraspinal muscles, it was labelled as high attenuation mucus impaction (HAM). On MRI, the inverse mucus impaction sign (IMIS), which is hyperintense on T1-weighted images and hypointense on T2-weighted images, was evaluated. HAM and IMIS were primarily searched within central airways. Only lung abnormalities were evaluated. Mediastinal abnormalities were not assessed. As there are no established criteria for lung MRI abnormalities, the CT criteria based on established nomenclature were adopted. Initially, the MRI images were reviewed. To reduce any recall and avoid bias in interpretation, the corresponding HRCT images were reviewed after one week of MRI assessment. For discrepant findings, a consensus reading was done.

Table 1
ISHAM-ABPA working group criteria [12].

Predisposing condition	Bronchial asthma, cystic fibrosis
Obligatory criteria (both should be present)	Type I Aspergillus skin test positive (immediate cutaneous hypersensitivity to Aspergillus antigen) or elevated IgE levels against Aspergillus fumigatus
	Elevated total IgE levels (> 1000 IU/mL)[a]
Other criteria (at least two of three)	Presence of precipitating or IgG antibodies against *A. fumigatus* in serum
	Radiographic pulmonary opacities consistent with ABPA[b]
	Total eosinophil count > 500 cells/μL in steroid naive patients (may be historical)

[a] If the patient meets all other criteria, an IgE value < 1000 IU/mL may be acceptable.
[b] The chest radiographic features consistent with ABPA may be transient (i.e. consolidation, nodules, tram-track opacities, toothpaste/finger-in-glove opacities, fleeting opacities) or permanent (i.e. parallel line and ring shadows, bronchiectasis and pleuropulmonary fibrosis).

Table 3
Over all Diagnostic Performance of lung MRI in ABPA.

Findings	Disease prevalence	Sensitivity	Specificity	PPV	NPV
Bronchiectasis	55.56%	68% CI 46.50% to 85.05%	100% CI 83.16% to 100.00%	100%	71.43%
Consolidation	17.24%	80% CI 28.36% to 99.49%	100% CI 85.75% to 100.00%	100%	96%
Nodules	34.29%	75% CI 42.81% to 94.51%	100% CI 85.18% to 100.00%	100%	88.46%
Mucus impaction	7.14%	100% CI 15.81% to 100.00%	100% CI 86.77% to 100.00%	100%	100%

(CI: Confidence Intervals).

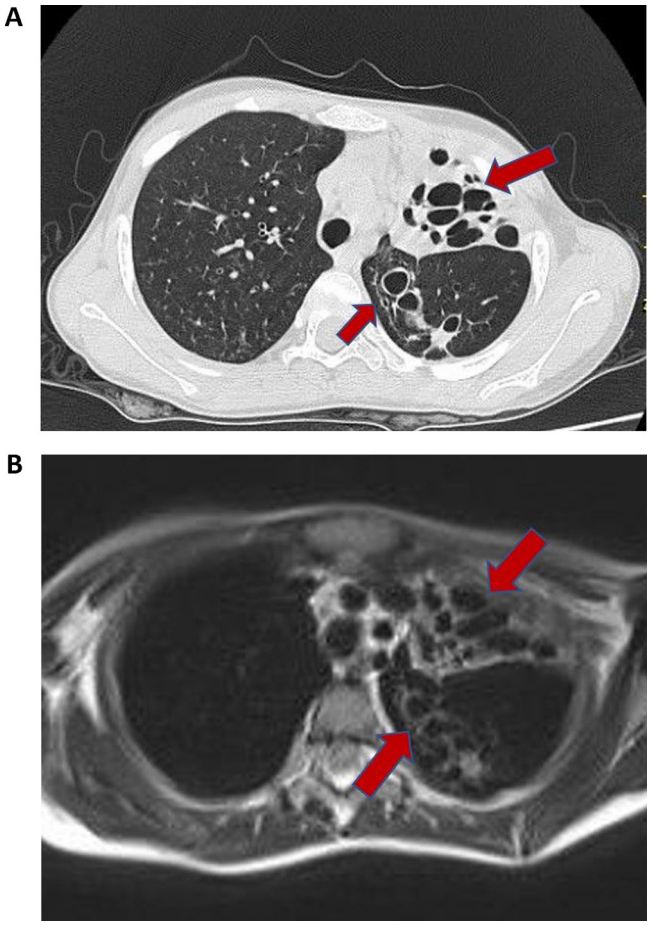

Fig. 1. Bronchiectasis: HRCT(A) and corresponding T2W MR images (B) of 7-year-old girl show extensive bronchiectasis (red arrows, A and B) in the apicoposterior segment of the left upper lobe (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.).

2.2.4. Statistical analysis

The sensitivity, specificity, positive and negative predictive values of MRI findings for parameters of interest was calculated for each finding. The agreement between the MRI and HRCT findings was assessed using the kappa test of agreement. To determine the differences between the two modalities, the McNemar test was used. Interobserver agreement was calculated using the kappa statistics. The degree of agreement was graded as slight ($k < 0.20$), fair ($k = 0.21–0.40$), moderate ($k = 0.41–0.60$), substantial ($k = 0.61–0.80$) and almost perfect ($k = 0.81–1.00$). A P-value of < 0.05 was considered statistically significant. The statistical analyses were conducted using SPSS software for Windows (version 22.0; SPSS Inc., Chicago, IL).

Funding: This study was funded by Indian Council of Medical Research (ICMR) vide research project Id ICMR-2012-2081.

3. Results

3.1. Patient characteristics

The mean age of the patients was 9.89 years (range: 5–16 years). There were 20 boys and 7 girls. All the children were diagnosed to have asthma that was poorly controlled. Type I hypersensitivity against Aspergillus fumigatus (by skin test) was positive in all patients. The median total IgE and Aspergillus fumigatus specific IgE levels were 3687 IU/mL (range, 68–10000 IU/mL) and 7.3 kUA/L (range, 0.03–39.7 kUA/L) (for diagnosis of ABPA, total IgE should be at least 1000 IU/mL and Aspergillus fumigatus specific IgE should be at least 0.35 kUA/L).

3.2. CT and MRI findings

All CT and MRI studies were diagnostically acceptable (25 MRI studies were graded as 2 and two MRI studies were graded as 1). All 27 CT studies were graded as 2. None of the imaging studies including CT or MRI had to be excluded due to artifacts. Table 2 summarizes the CT and MRI findings in 27 children with ABPA. CT was interpreted as normal in 17 patients. MRI was also reported as normal in these same 17 patients. Table 3 gives an overall statistical analysis.

The kappa test showed substantial to almost perfect agreement between MRI and HRCT studies for the detection of bronchiectasis, consolidation, nodules and mucus impaction across all the lobes (Table 5). No statistically significant difference was observed in findings detected on MRI and HRCT studies between the two modalities by the McNemar test ($P > 0.05$). The agreement between two observers for concordance between MRI and CT findings using the kappa statistics was almost perfect for consolidation, nodules and mucus impaction across all the lobes (Figs. 1 and 2) (Tables 4 and 5). There was substantial to almost perfect agreement for interpretation of bronchiectasis (Fig. 1). There was one patient with high attenuation mucus impaction on HRCT. Right lower and left lower lobes were involved. At both the lobes, both the observers correctly interpreted it as IMIS (Fig. 2).

4. Discussion

In children with chronic pulmonary diseases such as ABPA, imaging may be required on multiple occasions (in the event of exacerbations or for clinico-radiologic correlation over time).

Patients with ABPA often require imaging with CT (or MRI) primarily at baseline. Imaging is then also required every 4–5 years to ensure that bronchiectasis is not progressing despite treatment. Imaging is also required in refractory ABPA exacerbations or in glucocorticoid-dependent ABPA to exclude other causes. In patients with serological ABPA, CT is performed every 5 years to look for any development of bronchiectasis [13].

Multiple CT examinations lead to cumulative exposure to ionizing radiation.

Currently, MRI is the desired imaging modality for many conditions in children given the radiation-related concerns with CT. The results of this study suggest that MRI has good diagnostic utility in the diagnosis of radiological abnormalities seen in ABPA. Many recent studies have

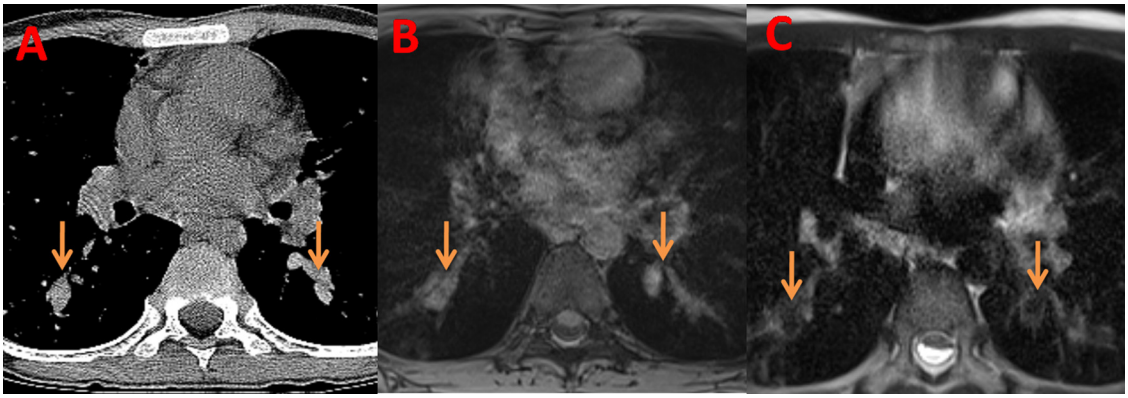

Fig. 2. High attenuation mucus (HAM) and inverse mucus intensity signal (IMIS): HRCT images of 11-year-old boy show bronchiectasis with high attenuation mucus impaction (arrows, A). Corresponding T1W and T2W MR images show high signal intensity on T1W (arrows, B) and low signal intensity on T2W images (arrows, C) characteristic of IMIS. This sign is suggested to be highly specific for ABPA.

Table 4
Kappa statistics for agreement between CT and MRI findings.

Finding	Kappa value
Bronchiectasis	0.7 CI 0.4363-0.87
Consolidation	0.9 CI 0.6183-1
Nodules	0.8 CI 0.5833-1
Mucus impaction	1.0 CI 1-1

(CI: Confidence Intervals).

Table 5
Kappa statistics for interobserver agreement for MRI findings.

Finding	Kappa value
Consolidation	1 CI 1-1
Bronchiectasis	0.9 CI 0.6183-1
Nodules	1 CI 1-1
Mucus impaction	1 CI 1-1

(CI: Confidence Intervals).

evaluated the role of MRI in thoracic diseases in children including pulmonary infections, tuberculosis, febrile neutropenia and interstitial lung diseases [5,6,9–11,20–28,14–31]. A high sensitivity, specificity as well as an excellent inter-observer agreement has been reported for most of the pulmonary abnormalities. A case report described MRI as a new paradigm in the evaluation of ABPA [32]. However, to the best of our knowledge, none of the studies have reported the diagnostic utility of MRI in the evaluation of children with ABPA.

Although MRI has inherent limitations, which include higher cost, availability, acquisition time and overall magnet time, need for sedation in younger childen, however, in developed countries and with advances in MR technology that provide faster image acquisition, it is highly desirable that this radiation free modality be explored and utilized to its full potential.

We could achieve diagnostic MRI in all children. We compared the diagnostic performance of MRI in comparison to CT for pulmonary findings in each lobe. MRI was able to diagnose abnormalities correctly in all patients, though when it came to detection of the overall total number of bronchiectatic lesions; it missed 8 bronchiectatic segments (lesions), which were detected at CT scan. However, significantly the radiological diagnosis was not altered in these patients as MRI had detected bronchiectasis in other lung segments in the same patient. However, for the purpose of statistical analysis, we have taken into account the total number of lesions (lobes involved). Hence, the sensitivity, specificity, PPV, and NPV of 3 T MRI for bronchiectasis was 68%, 100%, 100% and 71.43% respectively. The sensitivity, specificity, PPV, and NPV for consolidation was 80%, 100%, 100% and 96% respectively. For detection of nodules, the sensitivity, specificity, PPV, and NPV was 75%, 100%, 100% and 88.46% respectively. There was 100% sensitivity, specificity, PPV and NPV for mucus impaction. There was a high degree of interobserver agreement for MRI findings (k = 0.9–1) as well as agreement (k = 0.7–1) between CT and MRI for all the four findings.

Our results compare favourably with the previous studies. Gorkem et al, evaluated 71 children with various thoracic abnormalities including 21 children with infection [27]. They compared CT and MRI findings and reported sensitivity and specificity of 96% and 100%, respectively for MRI. Consolidation was correctly detected by MRI in all children while bronchiectasis and nodules were detected in 86% and 83% children respectively. In their evaluation of 75 children with pulmonary infections, Sodhi et al. compared the diagnostic performance of MRI [30]. Similar to the results of the present study as well as a study by Gorkem et al, consolidation was detected in all children. MRI detected bronchiectasis in 80% and nodules in 97% of cases. Twenty-six children with febrile neutropenia were evaluated in an earlier study by Sodhi et al, to compare CT and MRI [8]. A sensitivity and specificity of 100% were reported for MRI for the detection of consolidation and nodules. Other studies have also reported an excellent agreement between CT and MRI in children with cystic fibrosis and pulmonary tuberculosis [16,29]. The results of our study compare favourably with these findings.

High-attenuation mucus (HAM) is the pathognomonic finding of ABPA. HAM is said to be present if the density of mucus is more than the paraspinal skeletal muscle (generally ≥70 HU). The presence of HAM suggests that the underlying cause of bronchiectasis is ABPA [33].

The presence of HAM is also a marker of severe disease and indicates a patient with propensity for recurrent exacerbations [34].IMIS is a new sign described on MR in patients with CF-ABPA. The presence of IMIS identifies mucus that is abnormal and is encountered in those with CF-ABPA [35]. In the study by Dournes et al, MRI of the airway mucus contrast was used as a tool to diagnose ABPA in patients with cystic fibrosis [35]. The presence of mucus with both high T1 and low T2 signal intensities (referred to as inverted mucus impaction signal-"IMIS") was qualitatively and quantitatively evaluated in patients with cystic fibrosis. They reported IMIS sign in 17 patients and found a very good intra and inter-reader reproducibility. We found this sign in only one child (in two lobes) in the present study. This correlated well with the HAM on CT and was correctly identified by both the observers. The relative paucity of this sign in our study relates well to the rarity of these findings in both children and adults as reported in other studies. However, when detected, the finding of HAM on CT or IMIS on MRI should allow a confident diagnosis of ABPA.

There are a few limitations in this study. First, this is a relatively

small study group and a larger study group would have more reliability, however, it is disease-specific and it would be difficult to collect a similar disease-specific cohort in children who would fit into ABPA definition criteria easily and who require imaging. Also, more than 50% of children had normal imaging. This reduced the number of imaging abnormalities that could be evaluated. However, we have calculated sensitivity and specificity based on total number of lesions in pulmonary lobes rather than the number of children. Only one child had the MRI correlate of HAM (i.e. IMIS) in two lobes. As this sign is very specific for ABPA (though uncommon) a larger number of children with ABPA would have validated the MRI accuracy of this sign. A newer, ultrashort echotime MRI (UTE-MRI) sequence has been shown to accurately detect lung structural abnormailities, mucus plugs, bronchiectasis, consolidation and thickening of bronchial wall in CF patients that correlated well with CT scan [36]. However, we could not explore the utility of this UTE- MRI sequence in these children, as it is as yet not commercially available in our country.

In conclusion, based on our initial results, 3 T MRI has a high specificity, positive predictive value as well as substantial interobserver agreement for the diagnosis of imaging abnormalities in children with ABPA. However, it demonstrates lower sensitivity and negative predictive value when compared to CT scan, which is the currently accepted imaging gold standard. Newer MR sequences need to be explored and validated to enhance the potential of lung MRI in ABPA.

Conflict of interests

None.

Acknowledgements

This study has been funded by grants from Indian Council of Medical Research Vide project no.2012-2081.

ICMR funds provided for cost of acquisition of both CT and MRI in these children.

References

[1] I.S. Sehgal, R. Agarwal, Is treatment of serological ABPA similar to that of ABPA with bronchiectasis? J. Allergy Clin. Immunol. Pract. 5 (September–October (5)) (2017) 1474.
[2] G. Cortese, V. Malfitana, R. Placido, et al., Role of chest radiography in the diagnosis of allergic bronchopulmonary aspergillosis in adult patients with cystic fibrosis, Radiol. Med. 112 (5) (2007) 626–636.
[3] M.C. Pasteur, D. Bilton, A.T. Hill, British Thoracic Society guideline for non-CF bronchiectasis, Thorax 65 (Suppl 1) (2010) i1–i58.
[4] D.J. Brenner, E.J. Hall, Computed tomography-an increasing source of radiation exposure, N. Engl. J. Med. 357 (22) (2007) 2277–2284.
[5] K.S. Sodhi, E.Y. Lee, What all physicians should know about the potential radiation risk that computed tomography poses for paediatric patients, Acta Paediatr. 103 (8) (2014) 807–811.
[6] J. Biederer, S. Mirsadraee, M. Beer, et al., MRI of the lung (3/3)—current applications and future perspectives, Insights Imaging 3 (4) (2012) 373–386.
[7] V. Peltola, O. Ruuskanen, E. Svedstr€om, Magnetic resonance imaging of lung infections in children, Pediatr. Radiol. 38 (11) (2008) 1225–1231.
[8] K.S. Sodhi, N. Khandelwal, A. Saxena, et al., Rapid lung MRI: a paradigm shift in the evaluation of febrile neutropenia in children with leukemia: a pilot study, LeukLymphoma 57 (1) (2016) 70–75.
[9] J.H. Chung, B.P. Little, A.V. Forssen, et al., Proton MRI in the evaluation of pulmonary sarcoidosis: comparison to chest CT, Eur. J. Radiol. 82 (12) (2013) 2378–2385.
[10] J. Biederer, M. Beer, W. Hirsch, et al., MRI of the lung (2/3). Why. . . when. . . how? Insights Imaging 3 (4) (2012) 355–371.
[11] A. Hebestreit, G. Schultz, A. Trusen, et al., Follow-up of acute pulmonary complications in cystic fibrosis by magnetic resonance imaging, Acta Paediatr. 93 (3) (2004) 414–416.
[12] R. Agarwal, A. Chakrabarti, A. Shah, et al., Allergic bronchopulmonary aspergillosis: review of literature and proposal of new diagnostic and classification criteria, Clin. Exp. Allergy 43 (8) (2013) 850–857.
[13] R. Agarwal, A. Khan, A.N. Aggarwal, B. Saikia, D. Gupta, A. Chakrabarti, Role of inhaled corticosteroids in the management of serological allergic bronchopulmonary aspergillosis (ABPA), Intern. Med. 50 (8) (2011) 855–860.
[14] M.C. Liszewski, P. Ciet, K.S. Sodhi, E.Y. Lee, Updates on MRI evaluation of pediatric large airways, AJR Am. J. Roentgenol. 208 (5) (2017) 971–981.
[15] G. Serra, C. Milito, M. Mitrevski, et al., Lung MRI as a possible alternative to CT scan for patients with primary immune deficiencies and increased radiosensitivity, Chest 140 (6) (2011) 1581–1589.
[16] E.B. Rizzi, V. Schinina', M. Cristofaro, et al., Detection of pulmonary tuberculosis: comparing MR imaging with HRCT, BMC Infect. Dis. 11 (2011) 243.
[17] T. Heye, S. Ley, C.P. Heussel, et al., Detection and size of pulmonary lesions: how accurate is MRI? A prospective comparison of CT and MRI, Acta radiol. 53 (2) (2012) 153–160.
[18] U.I. Attenberger, J.N. Morelli, T. Henzler, et al., 3 Tesla proton MRI for the diagnosis of pneumonia/lung infiltrates in neutropenic patients with acute myeloid leukemia: initial results in comparison to HRCT, Eur. J. Radiol. 83 (1) (2014) e61–e66.
[19] C. Rieger, P. Herzog, R. Eibel, M. Fiegl, H. Ostermann, Pulmonary MRI—a new approach for the evaluation of febrile neutropenic patients with malignancies, Support. Care Cancer 16 (6) (2008) 599–606.
[20] J. Biederer, S. Mirsadraee, M. Beer, et al., MRI of the lung (1/3)—current applications and future perspectives, Insights Imaging 3 (4) (2012) 345–353.
[21] R. Eibel, P. Herzog, O. Dietrich, et al., Pulmonary abnormalities in immunocompromised patients: comparative detection with parallel acquisition MR imaging and thin-section helical CT, Radiology 241 (3) (2006) 880–891.
[22] K.S. Sodhi, M. Sharma, E.Y. Lee, et al., Diagnostic utility of 3T lung MRI in children with interstitial lung disease: a prospective pilot study, Acad. Radiol. (November) (2017), https://doi.org/10.1016/j.acra.2017.09.013 pii: S1076-6332(17)30406-3, [Epub ahead of print].
[23] W. Hirsch, I. Sorge, S. Krohmer, D. Weber, K. Meier, H. Till, MRI of the lungs in children, Eur. J. Radiol. 68 (2) (2008) 278–288.
[24] T. Rupprecht, B. Bowing, R. Kuth, M. Deimling, W. Rascher, M. Wagner, Steady-state free precession projection MRI as a potential alternative to the conventional chest X-ray in pediatric patients with suspected pneumonia, Eur. Radiol. 12 (11) (2002) 2752–2756.
[25] A. Yikilmaz, A. Koc, A. Coskun, et al., Evaluation of pneumonia in children: comparison of MRI with fast imaging sequences at 1.5T with chest radiographs, Acta Radiol. 52 (8) (2011) 914–919.
[26] Y. Ohno, H. Koyama, T. Yoshikawa, et al., Pulmonary high-resolution ultrashort TE MR imaging: comparison with thin-section standard- and low-dose computed tomography for the assessment of pulmonary parenchyma diseases, J. Magn. Reson. Imaging 43 (2) (2016) 512–532.
[27] S.B. Gorkem, A. Coskun, A. Yikilmaz, D. Zurakowski, R.V. Mulkern, E.Y. Lee, Evaluation of pediatric thoracic disorders: comparison of unenhanced fast-imaging-sequence 1.5-T MRI and contrast-enhanced MDCT, AJR Am. J. Roentgenol. 200 (6) (2013) 1352–1357.
[28] S. Montella, M. Maglione, D. Bruzzese, et al., Magnetic resonance imaging is an accurate and reliable method to evaluate non-cystic fibrosis paediatric lung disease, Respirology 17 (1) (2012) 87–91.
[29] K.S. Sodhi, M. Sharma, A.K. Saxena, J.L. Mathew, M. Singh, N. Khandelwal, MRI in thoracic tuberculosis of children, Indian J. Pediatr. 84 (9) (2017) 670–676.
[30] K.S. Sodhi, N. Khandelwal, A.K. Saxena, et al., Rapid lung MRI in children with pulmonary infections: time to change our diagnostic algorithms, J. Magn. Reson. Imaging 43 (5) (2016) 1196–1206.
[31] M.C. Liszewski, S. Görkem, K.S. Sodhi, E.Y. Lee, Lung magnetic resonance imaging for pneumonia in children, Pediatr. Radiol. 47 (11) (2017) 1420–1430.
[32] M.K. Garg, P. Gupta, R. Agarwal, et al., MRI: a new paradigm in imaging evaluation of allergic bronchopulmonary aspergillosis? Chest 147 (2) (2015) e58–e59.
[33] R. Agarwal, High attenuation mucoid impaction in allergic bronchopulmonary aspergillosis, World J. Radiol. 2 (1) (2010) 41–43.
[34] R. Agarwal, D. Gupta, A.N. Aggarwal, A.K. Saxena, A. Chakrabarti, S.K. Jindal, Clinical significance of hyperattenuating mucoid impaction in allergic bronchopulmonary aspergillosis: an analysis of 155 patients, Chest 132 (4) (2007) 1183–1190.
[35] G. Dournes, P. Berger, J. Refait, et al., Allergic bronchopulmonary aspergillosis in cystic fibrosis: MR imaging of airway mucus contrasts as a tool for diagnosis, Radiology 285 (1) (2017) 261–269.
[36] D.J. Roach, Y. Crémillieux, R.J. Fleck, A.S. Brody, S.D. Serai, R.D. Szczesniak, et al., Ultrashort echo-time magnetic resonance imaging is a sensitive method for the evaluation of early cystic fibrosis lung disease, Ann. Am. Thorac. Soc. 13 (11) (2016) 1923–1931.