A Practical Approach to Lung MRI at 1.5T

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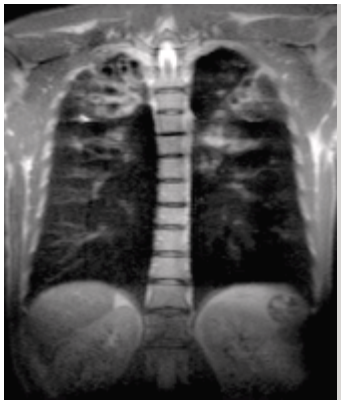
Introduction

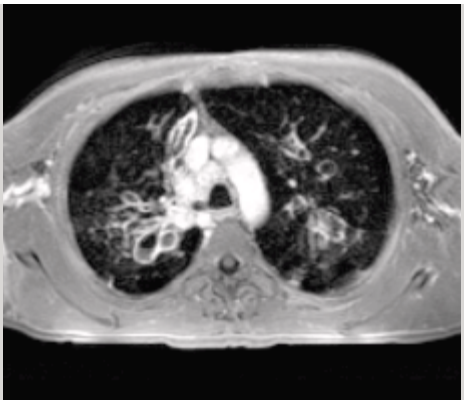
The value of MRI in imaging cardiac and large vessel disease is widely accepted, but the largest organ of the thorax, the lung, is usually investigated with X-ray and CT. MRI suffers from well-known limitations such as constant artifacts from heart pulsation or respiration and the low signal intensity of the aerated lung. This results from low overall proton density in combination with high susceptibility artifacts at air-tissue interfaces. The broadly accepted routine indications for MRI of the chest are instead focused on soft tissue processes such as chest wall masses or tumors of the mediastinum. The excellent contrast and the capacity of MR to produce cross sectional images or three-dimensional data sets in any orientation designate it as the ideal tool for this purpose. However, X-ray and CT are constantly criticized for the associated radiation exposure, in particular where applied for frequent follow-up examinations of children, or during pregnancy. A non-invasive method for follow-up of lung diseases during clinical trials or for physiologic research is therefore highly desirable. Since the recent technical developments in the field have contributed to overcome the well-known limitations of lung MRI, we can now recommend a comprehensive routine imaging protocol for the whole chest including lung parenchyma diseases.

Clinical method description

To match the criteria of a comprehensive imaging protocol for clinical routine, the recommended protocol needs to keep within a reasonable time frame of 15 to 30 minutes. It uses fast sequences for single- or multiple breathhold imaging and does not require cardiac or respiratory triggering. This facilitates patient positioning and shortens the room time. Limited information on cardiac pathology is provided with the single shot T2-HASTE and the free-breathing True-FISP. If further cardiac imaging is planned, ECG-triggering would be needed. The key to high image quality without respiratory motion artifacts is appropriate instruction of the patient. Nevertheless, the T2-HASTE as well as the free breathing TrueFISP are robust against breathing motion and can therefore be applied even with completely uncooperative patients. The vessel imaging capacity of the TrueFISP will even allow detection of large central pulmonary emboli in dyspneic patients. Only one sequence – the optional high-resolution – T2-TSE uses a navigator.

We present below a basic protocol for non contrast-enhanced MRI of the lung, followed by recommendations for additional contrast-enhanced and functional imaging (table 1). This would be applicable to children from 8–10 years and adults. For younger children, spatial resolution and Field of View





[Figure 1] *45-year-old male with cystic fibrosis of the lung. Bronchiectases in both upper lung lobes with mucous plugging being represented by bright signal on the T2-weighted HASTE (left image) and intermediate signal of the mucus within the bright signal of the contrast-enhanced bronchus walls in the transverse 3D-GRE (VIBE) sequence. For recommended sequence parameters see table 1.*

(FoV) would need to be adjusted. All components are based on common MR sequence components of current standard installations. In detail, they refer to 1.5T MAGNETOM Avanto protocols and a Body Matrix coil for thoracic imaging, but they would also be applicable to MAGNETOM Sonata and MAGNETOM Symphony installations with minimal adjustments. Where parallel acquisition techniques are not available, multi-breathhold acquisitions can be used instead. If a navigator is not available, a respiration belt could be used instead. For all coronal sequences (except for perfusion and angiography to save reconstruction time), distortion correction ("large FoV") is activated and excitation order is interleaved, where appropriate.

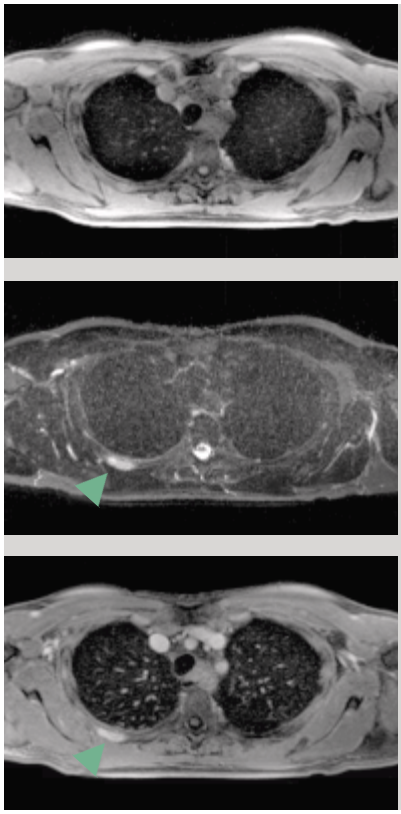
Basic protocol for non-contrast enhanced MRI of the lung

The imaging protocol starts with a gradient echo localizer in inspiration. The first sequences are acquired in breathhold, usually starting with the coronal T2-HASTE followed by the transverse T1-weighted 3D-GRE (VIBE). After this the first set of coronal SS-GRE sequences is acquired in free breathing, giving the patient some time to recover from the breathhold maneuvers. This is followed by the T2-TIRM image series, which is acquired with multiple breathholds. Anatomic coverage should include the upper abdomen with liver and adrenal glands. This basic protocol may be completed with the single slice dynamic SS-GRE series for diaphragmatic function. For this series, the patient is instructed to breathe deeply. Total room time up to here will be approximately 15 minutes.

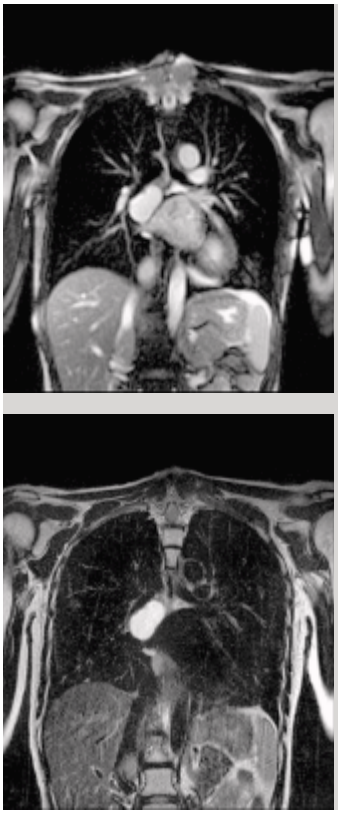
This basic protocol covers a range of routine indications, e.g. follow-up examinations in children with cystic fibrosis (Fig. 1) [1]. The sensitivity for lung nodules larger than 4 mm ranges

Indications for the basic protocol

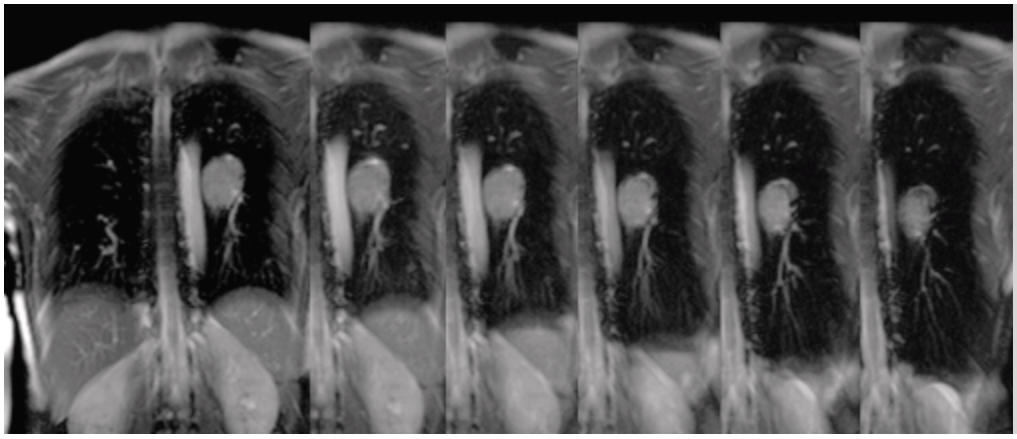
- pneumonia (T2-HASTE, TrueFISP)
- atelectasis (all sequences)
- cystic fibrosis (T2-HASTE, VIBE)
- tuberculosis (T2-HASTE, TrueFISP)
- nodule detection (TIRM, T2-HASTE, VIBE)
- mediastinal masses (VIBE, T2-TIRM)
  (lymphoma, goiter, cyst (Fig. 4), thymoma)
- interstitial lung disease (plus HR T2-TSE)
- diaphragmatic paralysis (TrueFISP)
- acute pulmonary embolism (TrueFISP)



[Figure 2] *62-year-old male with suspected bronchial carcinoma. Bone metastasis of the third right rib hardly detectable on the non-contrast enhanced VIBE, but with high signal on T2-TIRM and intensive enhancement after i.v. administration of contrast material.*



[Figure 3] *46-year-old female with suspected bronchial carcinoma after incidental detection of a hilar mass on chest x-ray. The single image of the coronal TrueFISP series (upper image) and the high resolution navigated T2-TSE image (lower image), both acquired during free breathing, show a well defined cystic formation in the lower part of the right hilus with water-equivalent signal of the content. Histology after surgical resection confirmed a bronchogenic cyst. For recommended sequence parameters see table 1.*



[Figure 4] *48-year-old female with suspected lung cancer. The dynamic TrueFISP series in coronal position demonstrates tumor and diaphragm motion during a deep inspiration maneuver. (left to right). For recommended sequence parameters see table 1.*

between 80 and 90% and reaches 100% for nodules larger than 8 mm [2, 3]. Depending on the water content, nodules can be detected either on the VIBE or on the HASTE and T2-TIRM images. Atelectasis and tumor can be well distinguished on T2-weighted sequences, especially if the high resolution T2-TSE is added. If MRI is applied for staging of lung malignancies with non-contrast enhanced images, T2-TIRM is an obligatory protocol component for the detection of bone metastases [4] (Fig. 2). The dynamic coronal TrueFISP acquisitions allow estimating diaphragmatic function and the mobility of intrathoracic masses (Fig. 3). This particular part provides additional functional information to the morphologic images and is one of the essential differences between lung MRI and any other common imaging modalities [5].

Basic protocol including contrast enhanced MRI of the lung

For routine purposes it might appear sufficient to conclude the study, if the non-enhanced scans show completely normal findings. Nevertheless, application of i.v. contrast material markedly improves the diagnostic yield of 3D-GRE imaging of the lung by the clearer depiction of vessels, hilar structures and pleural enhancement. Parenchymal disease and solid pathologies are also enhanced. Thus, a study to exclude pulmonary malignancies e.g. for staging purposes should usually comprise a contrast enhanced series, preferably with a fat-saturated 3D-GRE sequence. Contrast enhancement is also necessary for pleural processes (empyema, abscess, metastatic spread of carcinoma, mesothelioma) or for the further evaluation of solid masses, as well as for functional imaging or angiography. If it is intended to include a contrast-enhanced series, the 3D-GRE (VIBE) sequence in the pre-contrast series should be applied with fat-saturation to allow for a direct comparison of contrast uptake. Contrast material: 0.2 mmol/kg i.v. per hand or power injector. The contrast enhanced VIBE extends the range of indications for the protocol towards lung cancer and malignant and infectious pleural processes [6]. It is important to know that calcified nodules or masses may be invisible either on the non-contrast enhanced as well as on the contrast enhanced images. In most cases, this reflects benign findings but might be crucial e.g. for the staging of osteosarcoma.

Indications for additional CE-VIBE

- lung cancer
- pleural spread of carcinoma
- pleural effusion of unknown origin
- mesothelioma
- neurogenic tumours of the mediastinum
- mediastinitis
- vasculitis (e.g. Wegener's disease)

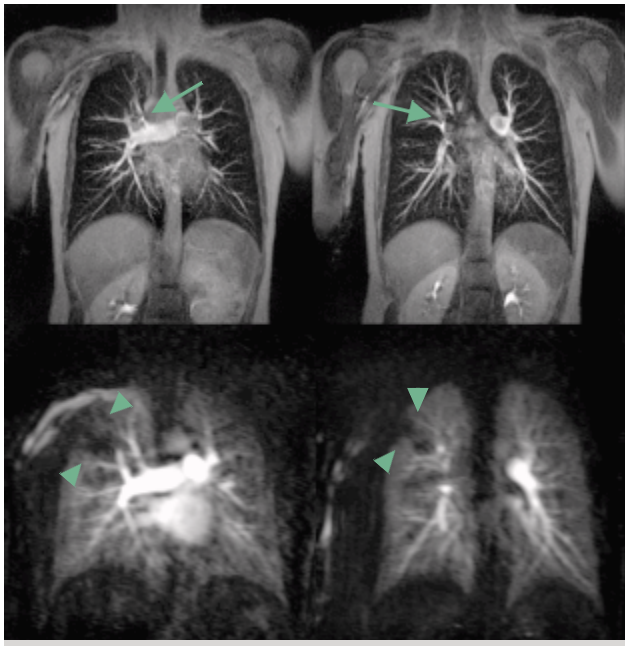
Lung perfusion imaging

The basic principle of contrast-enhanced perfusion MRI is a dynamic MR image acquisition following an intravenous bolus injection of a paramagnetic contrast agent. Perfusion MRI of the lung requires a high temporal resolution in order to visualize the peak enhancement of the lung parenchyma. The recommended fast acquisition technique is based on iPAT (integrated Parallel Acquisition Techniques) and data sharing. It allows for a 3D data acquisition with a temporal resolution of 1.5 seconds per image [7]. The resulting 4D-data set can be displayed with the "Mean Curve" application, which allows one to scroll through the series in a single image position or to scroll through the images of a 3D data set obtained at a single time point. A quick, semi-quantita-

Indications for perfusion MRI

- emphysema (indirectly)
- pulmonary hypertension
- acute and chronic pulmonary embolism

tive analysis of contrast-enhanced perfusion MRI data consists of the calculation of signal time curves, SNR and contrast-to-noise ratios (CNR) using region-of-interest (ROI) analysis of the signal of the lung tissue. For documentation, contrast-enhanced 3D perfusion MRI is usually processed by subtraction of mask image data acquired before contrast bolus arrival (Fig. 5). Since the acquisition time and diagnostic yield are at least the same as for a test bolus, the dynamic perfusion series may be used to prepare the angiogram. A disadvantage compared to the test bolus method is the additional time needed for image post-processing and the slightly higher amount of contrast medium (0.07 mmol/kg patient weight). To allow for an exact calculation of the time points for the angiograms, injection speed and the volume of the bolus plus sodium chloride chaser should be the same as for the following angiogram.



[Figure 5] *39-year-old female with suspected pulmonary artery hypertension. 10 mm MIP reconstruction of the coronal CE-MRA (3D-FLASH; upper pair of images) demonstrating small emboli in the right upper lobe artery as incidental finding (arrows). 20 mm MIP of the subtracted perfusion sequences (TREAT Perfusion, lower pair of images) show corresponding hypoperfusion in dependent parts of the right upper lung lobe (arrowheads). For recommended sequence parameters see table 1.*

Pulmonary angiography

Contrast-enhanced MRA uses a T1-weighted 3D-FLASH acquisition after intravenous injection of a paramagnetic MR contrast agent. A short TR allows for breathhold acquisitions and a short TE minimizes background signal and susceptibility artifacts. The flip angle of 25 degree produces a high contrast between lung tissue and the vessels. Adequate breathhold and exact timing of the contrast agent (0.1 mmol/kg at 5 ml/s followed by a 20 ml sodium chloride chaser, time to center 8.7 s) with an automatic power injector are essential prerequisites. Three acquisitions (non-contrast enhanced, centered on the peak signal of the pulmonary artery and centered on the peak signal of the aorta) are appreciated. For comprehensive viewing, we recommend use of the 3D-tool for multi planar reformation (MPR) or maximum intensity projections (MIP). The combination of 4D MRA perfusion and CE-MR angiography provides a useful alternative to perfusion scintigraphy and CT angiography, thus extending the range of indications for lung MRI by a considerable number of clinical conditions, e.g. suspected pulmonary embolism in pregnancy [8]:

Indications covered by lung CE-MRA

- pulmonary hypertension
- acute and chronic pulmonary embolism
- AV-malformation (e.g. M. Osler)
- pulmonary sequestration
- Swyer-James-Syndrom
- pulmonary artery aneurysms
- pulmonay vein anomalies
- masses of the hila
- tumour invasion a. pulmonalis / aorta

Respiration-triggered high resolution T2-TSE

Further options to extend the standard protocol are T1- and T2-weighted Spin Echo (SE) or Turbo Spin Echo (TSE) sequences with respiratory triggering (or gating). T1-weighted images are usually recommended for the detection of lymph nodes and tumor infiltration into the chest wall, but only the T2-weighted sequences contribute to the evaluation of lung

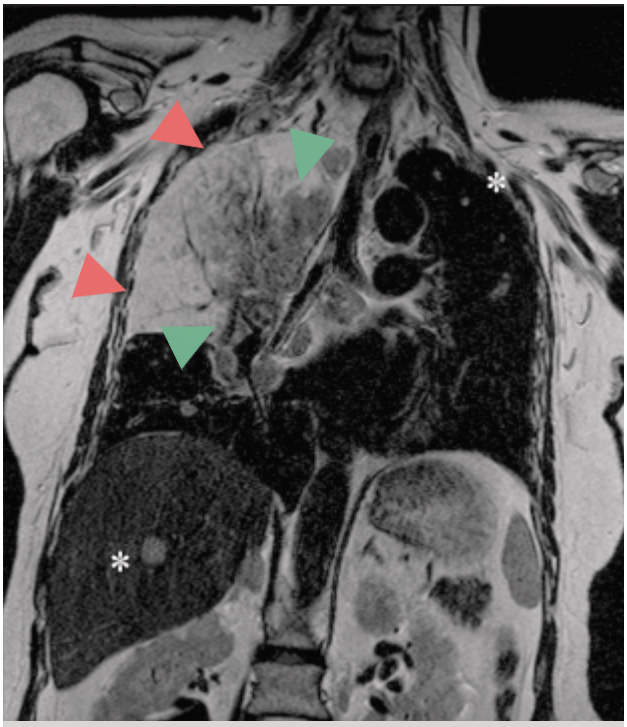
Indications to add HR-TSE

- interstitial lung disease
- lymphangitic spread of carcinoma
- differentiation of tumour/atelectasis
- masses with chest wall infiltration
- collateral findings (liver, adrenals)

parenchyma pathology and provide equal information about the chest wall and mediastinum. Since these triggered sequences are time-consuming, we recommend the inclusion of only one additional T2-TSE series into the protocol, since all aspects are covered by the previous sequences.

Conclusion

The proposed imaging protocol covers a wide range of clinical indications for lung imaging and may be used for routine purposes whenever it is mandatory to avoid radiation exposure as far as possible (e.g. in childhood and pregnancy). Moreover, its potential capacity to add functional information such as analysis of diaphragm motion and lung perfusion studies make it more that just a surrogate for chest x-ray and CT. The suggested sequences for lung MRI can be easily set up on state-of-the-art MR scanners by using the Phoenix sample files from www.siemens.com/MAGNETOM-World.



[Figure 6] *50-year-old female with large metastases from breast cancer. The T2-weighted respiration triggered TSE images show a clear difference of tumor (intermediate signal intensity on T2-weighted image green arrowheads) and atelectatic lung (high signal on T2-weighted image red arrowheads). Further pulmonary and hepatic metastases are indicated by stars. For recommended sequence parameters see table 1.*

Abbreviations

CE	Contrast enhanced
GRE	Gradient echo
HASTE	A Turbo Spin Echo technique
HR	High resolution
MRA	MR Angiography
SS GRE	Single shot gradient echo
TIRM	Turbo Inversion Recovery Magnitude
TrueFISP	a gradient echo sequence that provides the highest signal of all steady state sequences. FISP: Fast Imaging with Steady Precession
TSE	Turbo spin echo
TWIST	Time resolved 3D MR angiography
VIBE	Volume Interpolated Breathhold Examination

Further Reading

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Sequence parameters for MRI of the lung

	Non-CE lung MRI						Perf.	MRA	CE	T2-HR
Basic protocol 15'	x	x	x	x	x	x				(x)
Basic/CE 20'	x	x	x	x	x	x			x	(x)
Functional 30'	x	x	x	x	x	x	x	x	x	(x)
Siemens name	gre	haste	Fl3d _vibe	tfiseg	tse	tfiseg	Fl3d	Fl3d_ce _ce_ff	Fl3d _vibe	tse
Sequence	2D-Flash localizer	T2-HASTE	VIBE	True FISP	T2-TIRM	True FISP	4D MRA Perf.	3D-Flash Angio	VIBE	T2-TSE at
Respiratory phase	insp./bh.	insp./bh.	insp./bh	tidal	insp./bh	in./exp.	insp.	insp.	insp./bh	free
Slice orientation	c/t/s	cor	tra	cor	tra	cor	cor	cor	tra	cor
TA (min:s)	0:10	0:18	0:20	0:56	1:28	0:19	0:29	0:21	0:20	5:05+
Slices per acquisition	7	30	72	≤128	32x4	1	32x20	120	72	45
Preparation	A>P/R>L	R>L	A>P	R>L	A>P	R>L	R>L	R>L	A>P	R>L
FoV (mm) [FoV phase %]	500 [100]	450 [100]	400 [87.5]	450 [100]	400 [75]	400 [100]	500 [100]	500 [83.3]	400 [87.5]	500 [79.7]
Base resolution	256	256	256	256	320	256	256	384	256	512
Phase resolution (%)	75	100	100	100	75	66	54	90	100	75
Slice thickness (mm)	10	8	4	4	6	10	5	1.6	4	4
Phase partial Fourier	6/8	4/8	off	off	off	off	6/8	6/8	off	5/8
Pixel size (mm)	2.6x2.0	1.8x1.8	1.6x1.6	1.8x1.8	1.7x1.3	2.4x1.6	3.6x2.0	1.2x1.0	1.6x1.6	1.3x1.0
Distance factor	50%	0%	20%	-50/0%	10%	n.a.	20%	20%	20%	10%
TR (ms)	8.9	600	3.15	437.2	3500	317.1	1.64	2.75	3.15	1700
TE (ms)	4.38	31	1.38	1.16	106	1.14	0.64	1.12	1.38	100
Flip-angle (degr.)	30°	180°	8°	80	150	67	40	25	8°	150
Band width (Hz/pixel)	180	610	500	1030	252	980	1220	384	500	195
iPAT [no. of ref. lines]	0	2 [14]	2 [35]	2 [25]	2 [66]	2 [24]	2 [24]	2 [24]	2 [35]	2 [46]
Large FoV (dist. corr.)	off	on	off	on	off	off	off	off	off	on
Comments	cor/sag A>P/tra. R>L	2 concatenations ("interleaved")	FatSat, if CE VIBE is planned	Distance factor -50% WIP-Package	TI 150 ms, 5 concatenations	60 measurements at 3/second	20 measurements 1.5 s each. Reduce FA, if SAR limit exceeded	To be run pre-contrast and pul./aortic phase (8.7 s time to center)	With FatSat activated Identical with 3	Navigator needed 5 concatenations