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Contribution of magnetic resonance imaging in lung cancer imaging

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KEYWORDS
Thorax; Lung cancer; Magnetic resonance imaging; TNM staging; Diffusion-weighted images

Abstract
Lung cancer is the leading cause of cancer death worldwide. Prognosis and treatment outcomes are known to be related to the disease stage at the time of diagnosis. Therefore, an accurate assessment of the extent of disease is critical to determine the most appropriate therapy. Currently available imaging modalities for diagnosis and follow-up consist of morphological and functional imaging. Morphological investigations are mainly performed with CT-scan and in some cases with MRI. In this review, we describe the contribution of MRI in lung cancer staging focusing on solid pulmonary nodule characterization and TNM staging assessment using chest and whole-body MRI examinations, detailing in each chapter current recommendations and future developments.

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Lung cancer is the leading cause of cancer death worldwide. Prognosis and treatment outcomes are known to be related to the disease stage at the time of diagnosis\textsuperscript{[1]}. Therefore, an accurate assessment of the extent of disease is critical to determine the most appropriate therapy. Currently available imaging modalities for diagnosis and follow-up consist of morphological and functional imaging. Morphological investigations are mainly performed with computed tomography (CT) and in some cases with magnetic resonance imaging (MRI). Given its adequate spatial resolution and wide availability of this imaging modality, chest CT-scan is the primary and most commonly used modality for early diagnosis and initial staging of patients with lung cancer based on morphologic criteria. Recent CT developments involve perfusion and spectral imaging with promising results on tissue characterization.

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Functional investigations are dominated by 18-fluorodeoxyglucose positron emission tomography CT (\(^{18}\text{FDG PET-CT}\)) using \(^{18}\text{FDG}\) uptake and by the recently emergent whole-body MRI including morphological and functional sequences such as diffusion-weighted imaging (DWI). \(^{18}\text{FDG-PET-CT}\) has demonstrated efficacy in the initial staging of lung cancer with a variable avidity and limited spatial resolution in the detection of adenocarcinomas, with a considerable number of false-positive findings due to inflammatory changes and chronic disease [2]. Other limitations of \(^{18}\text{FDG-PET/CT}\) are brain staging and the fact that it is associated with a considerable radiation burden to patients and medical personnel. The radiation dose for a chest CT-scan varies between 1—10 mSv while that of whole body \(^{18}\text{FDG-PET/CT}\) is 10—30 mSv.

MRI is currently the only technique that enables non-invasive whole-body assessment without ionizing radiation. Moreover, in case of significant renal impairment if other modalities are considered inadequate and there is a clinical benefit of a contrast enhanced imaging procedure, we prefer the use of enhanced MRI than enhanced CT [3].

MRI has superior soft tissue contrast with high spatial resolution but it is more susceptible to cardiac and respiratory motion artifacts, affected by low proton density, very short T2* values, and inhomogeneity of the magnetic field in the lungs. However, recent advances in MRI techniques and the use of gadolinium chelates have improved the diagnostic capabilities of MRI in detecting and staging lung cancer. MRI provides not only morphologic but also functional information with diffusion-weighted and perfusion sequences. DWI has been put forward in the past few years as a new technique for evaluating nodal involvement. This technique can provide qualitative and quantitative information about the integrity of cell membrane and tissue consistency, which reflects changes at a cellular level [4].

In this review, we describe the contribution of MRI in lung cancer staging focusing on solid pulmonary nodule characterization and TNM staging assessment using chest and Whole-body MRI examinations, detailing in each chapter current recommendations and future developments.

**MRI technique**

We are distinguishing two types of sequences: morphological and functional. Artifacts generated by breathing and cardiac motions can be solved with consecutive breath-hold technique and with the use of respiratory cycle and/or cardiac gated imaging.

**Morphological sequences**

Due to respiratory artifacts we prefer the use of breath-hold sequences, which is possible with the use of parallel imaging methods and/or slice interpolation techniques. These sequences enable full lung volume coverage with slice thickness of 3 to 5 mm acquired during consecutive breath holds (e.g. VIBE “Volume Interpolated Breath-hold Examination” for Siemens; LAVA “Liver Acquisition with Volume Acceleration” for GEMS etc.). It can be performed on 2D or 3D, with or without fat suppression or with a DIXON technique (Water, Fat, In-Phase, Out-Phase) for anatomical and tissue characterization. Non-contrast enhanced images are preferably acquired without fat suppression or with Dixon technique to facilitate the detection of lymph nodes within the mediastinal fat or the extension within the chest wall. Enhanced images are preferably acquired with fat suppression, increasing the signal difference with the fat around the lesion and showing more precisely the heterogeneity of the enhancement.

Other T1 sequences to be used are the Fast Spin-Echo T1-weighted imaging (FSE T1-WI), the same sequence used for the spine or spinal cord exploration. The spatial resolution has to be increased by reducing slice thickness (2 to 3 mm) and the field of view (240 mm). To preserve the signal to noise ratio, the number of excitations (3 to 5) has to be increased. These sequences are very helpful to identify the tumor extension through the chest-wall especially in the superior sulcus tumor.

Breath-hold short tau inversion recovery (STIR) and free-breathing STIR are used in transverse or coronal plane in the whole body exploration. For sulcus tumor exploration this sequence has to be used in free breathing, in the sagittal plane with 4 to 5 mm slice thickness.

Rotating phase encoding T2-WI (T2 Propeller ‘‘Periodically Rotated Overlapping ParallelEL Lines with Enhanced Reconstruction’’ for GEMS; BLADE for Siemens) produces images with correction of respiratory and cardiac motion artifacts. This sequence can be used in breath-hold or respiratory triggering with or without fat suppression.

**Functional sequences**

In lung cancer imaging functional MRI has a dual role: exploration of the macroscopic motion (cardiac and respiratory movements) and microscopic random motion (diffusion imaging). Tumor perfusion with MRI for lung cancer is not yet fully developed for clinical use.

Images obtained during the cardiac cycle (same MRI sequence used to evaluate the cardiac function) allow dynamic visualization of structure mobility (cardiac chambers or great vessels of the mediastinum) in contact with the tumor. These sequences are cardiac-gated usually with breath-hold technique. Slice position has to be perpendicular to the interface between the tumor and the vascular structure.

To identify structure mobility in contact with the chest wall, as a very sensitive sign of chest wall involvement by the tumor, we have to obtain dynamic images during multiple consecutive respiratory cycle with deep inspiration followed by deep expiration, called as Respiratory Dynamic MRI. Using sequences of high temporal resolution (acquisition time for one slice < 0.5 second), allows us to obtain a sufficient number of images during one respiratory cycle. Images obtained during a multiple respiratory cycle permit the visualization of the tumor shift in contact with the chest wall in order to rule out the chest wall invasion by the tumor. Adequate sequences for this exploration are for instance FIESTA (Fast Imaging Employing Steady State Acquisition) for GEMS and HASTE (Half-Fourier Acquired Single-shot Turbo spin Echo) for Siemens.
DWI is based on the diffusion properties of water molecules and reflects tissue parameters like cellular density especially in tumor and tissue architecture. The apparent diffusion coefficient (ADC) is a parameter that refers to the specific diffusion capacity of a biological tissue proved to be useful in differentiating benign from malignant soft-tissue masses. Yet there is a lack of consensus regarding the optimal ADC cutoff value between benign and malignant lesions. Clearly, different magnetic strengths, imaging sequences and b values lead to different ADC values. Moreover, Wang et al. [5] reported that it was difficult to measure accurately the ADC values of lesions located adjacent to air-containing organs because of susceptibility artifacts caused by the heterogeneities of the magnetic field.

Dynamic contrast-enhanced (DCE) MRI has also been used to differentiate benign from malignant nodules [6,7] with moderate sensitivity and specificity and high accuracy of 76–100%, 70–100%, and 80–95%. In comparison to benign, malignant lesions showed higher values of maximum enhancement, early peak, slope and 4th minute enhancement. Early peak > 15% showed 100% sensitivity to detect malignancy, maximum enhancement > 40% showed 100% specificity [6].

In our institution this wide range of available morphological and functional sequences has been narrowed down to a few protocols (Table 1). The aim of these protocols is to adjust and perform accurate sequences that answer the clinical questions within less than a 20 minutes’ acquisition time. DCE-MRI is not routinely used in our institution.

Nodule characterization

MRI has been used for tissue characterization as a non-invasive exploration as additional exploration to CT-scan and 18FDG-PET/CT. It proofs useful in situations where the appearance of the nodule or mass on CT-scan is highly suspicious of malignancy with 18FDG uptake on PET-CT. The combination of these two findings is in favor of a malignant lesion. In some situations, MRI would make a diagnosis of benign lesion avoiding the need of histological proof (percutaneous biopsy or surgery) in patients whose lung function is often limited. This is proven for silicotic masses (Fig. 1), pseudotumor lipid pneumonia, tuberculosis, and hamartochondromas. With the use of a basic MRI protocol we can differentiate these diseases from a malignant pathology. To improve the limitations of morphological MRI, DCE-MRI may help differentiate malignant from benign pulmonary nodules. However, one prospective assessment of dynamic MRI showed the inadequacy of this technique for differentiating among indeterminate pulmonary nodules [8]. Further studies are necessary in order to validate the real clinical value of this technique.

DWI can be used to differentiate malignant from benign lesions on the basis of tissue cellularity. In a recent meta-analysis, Shen et al. [9] have reported that malignant pulmonary lesions have significantly lower ADC values than benign lesions [1.21 (95% CI: 1.19–1.22) mm²/s vs. 1.76 (95% CI: 1.72–1.80) mm²/s; P < 0.05]. There is a significant difference between ADC values of small cell lung cancer and non-small cell lung cancer (P < 0.05), while ADC measurements could not help differentiate subtypes of NSCLC. This may be explained by the fact that, although tumor cellularity strongly affected the ADC values, this biological parameter did not determine the histological classification; otherwise, histological type is mostly established based on other factors, such as keratinization, stratification, and cellular atypias. The size of nodules according to this meta-analysis was larger than 10 mm.

Benign nodules

Nodule behavior in DWI without ADC restriction, peripheral contrast enhancement and slight hypo-intensities in T2-WI are in favor of the diagnosis of tuberculoma in patient with apical lung sequelae. A very low signal intensity speculated mass or total lack of its visualization on T2-WI, showing iso-signal intensity on T1-WI compared with the signal intensity of skeletal muscles, and with a massive contrast enhancement is in favor of progressive massive fibrosis due to pneumoconiosis and silicosis (Fig. 1).

Gradient-echo in and out-of-phase sequences are used to highlight the fat content of pulmonary lipoma, hamartoma and pseudotumor in lipid pneumonia.

With DCE imaging, benign nodules, such as granulomas, tuberculomas, and hamartomas, tend to have weaker enhancement and slow washout comparing to malignant nodules. Conversely, organizing pneumonia and inflammatory nodules tend to have a rapid increase in enhancement and a gradual decrease in signal intensity after reaching the peak.

Malignant nodules

Malignant tumors are hyper-intense on T2-WI, iso-intense on T1-WI with restricted diffusion and ADC values less than 1.21 mm²/s [9], usually with homogenous contrast enhancement, that could be heterogeneous in relation to the size of the lesion. Heterogeneous tumor MRI signal intensities may represent hemorrhage, hypercellularity, and lack of cellular cytoplasm or tumor necrosis, particularly in large tumors (Fig. 2).

In dynamic contrast-enhanced imaging, malignant nodules tend to have stronger enhancement with faster upslope, higher maximum peaks, and rapid or gradual washout, comparing to benign nodules.

TNM Staging

T-staging assessment

The main challenge on CT-scan T-staging in lung cancer is the chest-wall and spine involvement, tumor extension to the mediastinum, to the large vessels and cardiac cavities. Other factors influencing the T-staging could be accurately identified by CT-scan and bronchoscopy.

MRI is currently recommended in the assessment of lung cancer extension to the chest wall (Fig. 3) especially of the superior sulcus tumor [10], to the spine, and to the cardiac cavities. The reliability of conventional CT-scan for
**Table 1** Protocol selection for lung cancer.

<table>
<thead>
<tr>
<th>Sequence type</th>
<th>3D-GE T1-WI (Dixon if possible)</th>
<th>T1-WI</th>
<th>STIR</th>
<th>FSE T2W/rotating phase encoding</th>
<th>Diffusion weighted imaging</th>
<th>Cine MR (ECG triggering)</th>
<th>Steady State GRE</th>
<th>3D-GE T1-WI with Echo sharing</th>
<th>3D-GE T1-WI</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Slice orientation</strong></td>
<td>Transverse</td>
<td>Sagittal and/or transverse</td>
<td>Sagittal or perpendicular to the tumor/chest-wall interface</td>
<td>Transverse</td>
<td>Transverse</td>
<td>Perpendicular to the tumor/vessel interface or heart cavity</td>
<td>Perpendicular to the tumor/chest-wall interface</td>
<td>Coronal</td>
<td>Transverse Coronal Sagittal</td>
</tr>
<tr>
<td><strong>Slice thickness, mm</strong></td>
<td>2 to 4 Breath-hold</td>
<td>2 to 3 Free breathing</td>
<td>3 to 4 Free breathing</td>
<td>5 to 6 Respiration triggered</td>
<td>5 to 6 Respiration triggering</td>
<td>5 to 6 Breath-hold</td>
<td>5 to 6 Deep inspiration and expiration slowly</td>
<td>2 to 4 Breath-hold or shallow breathing</td>
<td>2 to 4 Breath-hold</td>
</tr>
<tr>
<td><strong>Respiration</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>IV contrast</strong></td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td><strong>Covered area</strong></td>
<td>Whole thorax</td>
<td>Contact area of the tumor with the chest wall</td>
<td>Contact area of the tumor with the chest wall</td>
<td>Whole thorax</td>
<td>Contact area of the tumor with great vessels or heart cavities</td>
<td>Whole thorax</td>
<td>Contact area of the tumor with great vessels or heart cavities</td>
<td>Whole thorax</td>
<td>Whole thorax</td>
</tr>
<tr>
<td><strong>Acquisition time, min</strong></td>
<td>&lt; 1</td>
<td>2 to 4</td>
<td>3 to 5</td>
<td>5 to 6</td>
<td>5 to 6</td>
<td>&lt; 5</td>
<td>&lt; 2</td>
<td>&lt; 1</td>
<td>3 to 4</td>
</tr>
<tr>
<td><strong>Commentary</strong></td>
<td>Could be used in multiple breath-hold</td>
<td>Could be used in multiple breath-hold</td>
<td>Could be used with free breathing</td>
<td>Very high temporal resolution (&lt; 0.5 s/slice)</td>
<td>Dynamic MR angiography</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>General question/thoracic mass</strong></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td><strong>Mediastinal and/or great vessel invasion</strong></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td><strong>Chest-wall invasion</strong></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td><strong>Sulcus tumor (Pancoast-Tobias)</strong></td>
<td>X</td>
<td>Xa</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

"X" indicates the sequence for each clinical situation.

a To provide a better detection of chest-wall involvement by the tumor by decreasing the partial volume artifact, SE T1-WI has to be performed perpendicular to the tumor/chest-wall interface.

b For sulcus tumor, the sagittal T1-WI has to cover from the middle of spinal body to the external border of the tumor.
Contribution of MRI in lung cancer imaging

Figure 1. 75-year-old male, a former coal worker, non-smoker: a: axial CT-scan shows a solid pulmonary nodule with speculated margins (arrow) on parenchymal window; b: axial 18F-FDG PET/CT image with high 18FDG uptake of the nodule (arrow) and mediastinal lymph node (arrowhead), suspicious for malignancy; c: axial T2-weighted image with fat suppression does not identify the nodule related to the fibrous component of the nodule; d: axial Diffusion-weighted image (b = 1000 s/mm²) does not show any signal abnormalities within the nodule. No modification of the nodule and lymph nodes after 5 years follow-up.

assessment of chest wall invasion varies from 38 to 87% and specificities from 40 to 90%. MRI is superior to CT in the visualization of tumor extension to the chest wall, extending into the foramina and spinal canal, and the involvement of the brachial plexus, considering its multiplanar capability and especially a better tissue contrast resolution [11].

Direct MRI signs of chest-wall invasion are mass lesion adjacent to the chest wall with lytic bone destruction. Chest-wall invasion appears typically iso-intense to muscle

Figure 2. A 65-year-old male, heavy smoker with progressive dyspnea: a and b: axial CT-scan shows a spiculated solid nodule (arrow) on parenchymal window with a right hilar lymph node (*); c: axial DWI shows hyper-signal intensity of the nodule (arrow) and the mediastinal adenopathies (*). Needle biopsy of the mediastinal adenopathies showed adenocarcinoma.
Figure 3. A 56-year-old male patient with a 2-month history of a left posterior chest pain: a: posteroanterior chest radiograph demonstrates a left apical mass; b: sagittal multiplanar reconstruction of enhanced CT-scan shows a suspicious invasion foramina (2nd and 3rd left ribs) with disappearance of the low-density fatty separation planes (*); c and d: sagittal and coronal T1WI shows the lack of high signal intensity of fat in the foramina (*). This finding is related to intervertebral foramina invasion by the thoracic tumor; e and f: enhanced sagittal and coronal T1WI shows contrast enhancement of the foraminal space (*) and the subpleural space. Patient underwent chemo radiotherapy with a stable disease at the 2-month morphological evaluation but increasing chest pain. A decision was made to perform surgery. The pathology report showed positive margins in the region of the foramina confirming the MRI findings. Two months later, recurrence of the left thoracic pain, an MRI has been performed; g and h: enhanced axial and sagittal T1WI (Lava Flex) show the tumor recurrence within the foraminal space (*); i: left parasagittal T1WI (Lava Flex) shows a nodular pleural metastasis (arrow).
on T1-WI with interruption of physiological sub-plural and chest wall fat planes [12]. On fat-suppressed T2-WI the tumor would appear as a heterogeneous mass lesion with hyper signal intensity.

Note that the rib extension comes with the disappearance of spontaneous hyper signal intensity of bone marrow on T1-WI and the appearance of hyper-intense signal intensity on STIR (fatty marrow infiltration by the tumor or inflammation). The analysis is facilitated by comparison with normal adjacent ribs. The interruption of the cortex is a more specific but less sensitive than bone marrow infiltration.

Lung cancer appears with high signal intensity on STIR sequence within the suppressed signal intensities of chest wall structures. This can be further enhanced by the administration of intravenous contrast and other techniques such as dynamic contrast-enhanced MRI.

The use of respiratory dynamic MRI [11,12] increases the sensitivity and specificity to 100% and 82.9%, respectively. By viewing the images in cine mode, we look for the presence or absence of the mass shift on the chest wall during breathing cycle respectively signing the absence or presence of a parietal invasion. The false-positive results are secondary to benign adhesions between the visceral and parietal pleura.

A comparative study shows sensitivity, specificity, and accuracy of dynamic cine MRI for the detection of chest wall invasion of 100%, 70%, and 76%, respectively, when those of conventional CT were 80%, 65%, and 68% [12].

For the assessment of mediastinal invasion a study [13] comparing contrast-enhanced CT-scans, cardiac-gated MRI, and non-cardiac-gated and cardiac-gated contrast-enhanced MR angiographies shows sensitivity, specificity, and accuracy of contrast-enhanced MR angiography of 78% to 90%, 73% to 87%, and 75% to 88%, respectively, for detection of mediastinal and hilar invasion (Fig. 4). These values were higher than those of contrast-enhanced single helical CT and conventional T1-weighted imaging.

However, MDCT including MPR images has been used for T classification in routine clinical practice. Compared with MDCT, MRI is considered to have superior tissue contrast. Therefore, further investigations and comparative studies of thin-section MPR imaging and MRI are necessary to determine the actual significance of MRI for assessment of chest wall invasion in routine clinical practice.

**N-Staging assessment**

CT is used widely as the primary standard imaging modality for evaluating nodal status. However, it is unreliable for assessing lymph node involvement on the basis of only size criteria (i.e., whether the short-axis diameter of nodal lesion on a CT scan is > 1 cm). The sensitivity and specificity of CT for staging of lung cancer are relatively low, only 57% and 82%, respectively [14] The size criterion on morphological MRI is as accurate as CT-scan.

Ohno et al. [15] demonstrated that STIR turbo SE imaging is at least as valid as co-registered 18F-FDG-PET/CT for quantitative and qualitative assessment of the N-stage for non-small cell lung cancer patients. The metastatic lymph nodes are recognized by having high signal intensity on this sequence, compared with the non-metastatic nodes, which have low signal intensity.

With regard to DWI, several studies and meta-analysis [16–18] have confirmed the potential of DWI in the characterization of mediastinal node involvement using either visual assessment (Fig. 5) or ADC measurements.

Furthermore, Nomori et al. [17] showed that DWI was significantly more accurate than 18F-FDG-PET/CT in the N-staging of NSCLC because of less over staging and fewer false-positive results in the former. In this series, inflammatory lymphadenitis usually showed increased FDG uptake but not restricted diffusion, which justifies the difference in false-positive results between both techniques.

In a meta-analysis, Wu et al. [18] showed that DWI has a high specificity for N staging of NSCLC compared with 18F-FDG PET/CT and has the potential to be a reliable alternative noninvasive imaging method for the preoperative staging of mediastinal and hilar lymph node in patients with NSCLC. The pooled sensitivity estimate of DWI (0.72, 95% CI: 0.63–0.80) was not significantly different between PET/CT (0.75, 95% CI: 0.68–0.81; P = 0.09). The pooled specificity estimate for DWI (0.95, 95% CI: 0.85–0.98) was significantly greater than 18F-FDG PET/CT (0.89, 95% CI: 0.85–0.91; P = 0.02).

However, lymph nodes with a long axis diameter of less than 5 mm were not able to be detected on DWI. Also, there were lymph nodes with micrometastasis that were not detected as abnormal signal intensity lesions. In addition, ADC measurements of lesions can be affected by the necrosis, abscesses, and thrombi, which are believed to impede the diffusivity of water molecules. The apparent diffusion coefficients of necrotic lymph nodes with metastasis are relatively higher.

To summarize, in our experience, the ADC value of metastatic lymph nodes is usually comparable to the ADC value of the tumor with a variability of 20% admitted.

**M-Staging assessment**

With recent advances in MRI, whole body MRI with DWI is emerging as a single, cost-effective imaging technique comparable to that 18F-FDG-PET/CT for staging patients with metastatic carcinoma [19].

The detection of distant metastases is of crucial importance because it usually implies a poor prognosis. These patients are generally treated with chemotherapy and/or radiation, as curative surgical resection of the primary tumour is not a consideration.

18F-FDG-PET/CT is not suitable for the detection of brain metastases, as the sensitivity of 18F-FDG-PET/CT is low owing to the high glucose uptake of normal surrounding brain tissue. Being more sensitive and specific than CT [20], contrast enhanced MRI remains the method of choice for screening brain metastases with particular advantages in showing lesions in the posterior fossa and adjacent to the skull.

In liver metastasis, MR imaging with gadolinium chelates offers an accurate non-radiation based imaging test [21]. The diagnostic performance of DWI in liver metastasis is equal to that of enhanced-MRI. DWI alone can be used in patients where gadolinium contrast administration is
Figure 4. A 47-year-old male patient was admitted for hemoptysis. CT-scan showed a tumor in contact with the aorta and the left subclavian artery, complementary MRI was performed: a: axial T2WI shows the tumor (T) and its contact (more than 180°) with the subclavian artery (*); b and c: sagittal T1WI without (b) and with ECG gating (d) to reduce movement artifacts. The tumor (T) and the aortic arch (*) are well identified with the ECG-gated and breath-hold sequences; d and e: unenhanced (d) and enhanced (e) coronal T1WI shows the direct contact between the tumor (arrow) and the aorta (*) without aortic invasion; f and g: enhanced sagittal and axial T1WI confirms tumor contact with the aorta and the subclavian artery without MRI signs of invasion.
Figure 5. A 52-year-old patient was admitted for the exploration of a left upper lobe nodule: a: posteroanterior chest X-ray shows a well-defined peripheral left apical nodule (*); b and c: axial (b) and coronal multiplanar reconstruction images (b) of enhanced CT-scan shows a suspicious invasion of the intercostal space (arrow); d–f: axial (d), coronal (d) T2WI (Propeller sequence) and enhanced T1WI (Lava Flex) shows the nodule in contact to the chest-wall without MR signs of invasion. The coronal sequence was acquired perpendicular to the interface between the nodule and the chest-wall; g and h: axial T2WI (g) and enhanced T1WI (h) shows latero-aortic lymphadenopathy (arrow) staged as N2; i and j: axial DWI shows diffusion restriction of the nodule (arrow) and lymphadenopathy (arrow). Surgery confirms malignancy and the spread of tumor to the lymph node classifying the tumor as T2N2M0.
not allowed. Combination of enhanced-MRI and DWI significantly increases diagnostic accuracy in liver metastasis [22].

Adrenal nodule or masse in lung cancer is a frequent finding. The goal of a radiologist is to differentiate the adrenal adenoma from adrenal metastases. Adrenal adenoma has a characteristic histology with the presence of intracellular fat leading low density on unenhanced CT-scan (< 10 UH), however in up to 50% the density is higher than 10 UH and the diagnosis on CT-scan is hazardous. Chemical shift MRI could be successfully used in the characterization of adrenal lesions. By using different time parameters during the same MRI examination, it is possible to identify lipid-rich adenomas. These adenomas show signal loss on out-of-phase imaging, as opposed to imaging when the protons are in phase. In contrast, non-adenomas do not show signal loss on out-of-phase imaging [23]. Recent studies have shown that 60 to 89 percent of lesions measuring between 10 and 30 HU on unenhanced CT can be characterized using chemical shift MRI [23,24].

MRI is accurate for diagnosing skeletal metastases, and previous limitations have been overcome with the introduction of whole-body MRI [25,26].

The use of whole-body DWI is suggested for oncology imaging. When this technique is adapted for M-stage assessment including brain metastasis in NSCLC, the diagnostic accuracy of whole-body MRI with DWI (87.7%) showed no significant difference from that of integrated 18FDG-PET/CT (88.2%) on a per-patient basis. The accuracy of integrated 18FDG-PET/CT (90.4%) was significantly higher than that of whole-body MRI without DWI (85.8%) with brain metastasis excluded [25].

In a recent study, Sommer et al. [26] compared the diagnostic value of whole-body MRI including DWI for preoperative staging assessment of NSCLC with that of 18FDG-PET/CT. They reported that there were no significant differences between MRI and 18FDG-PET/CT (66% for MRI and 74% for 18FDG-PET/CT). Therefore, whole-body MRI with DWI could be used for M-stage assessment in patients with NSCLC with accuracy as reliable as that of integrated 18FDG-PET/CT.

**Therapeutic follow-up**

MRI has potential in postoperative lung function assessment involving the evaluation of ventilation and perfusion [27,28] for which 3D DCE-MRI is generally used although further studies are necessary. DCE-MRI is a useful predictor of tumor treatment response in NSCLC patients after chemoradiotherapy according to Chang et al. [29].

DWI findings have been reported to have prognostic value not only in the detection but also in the follow up of lung cancer. Early ADC changes observed after the initial chemotherapy course reportedly correlated with the final tumor size reduction [30]. In addition, they reported that the median progression-free survival for the group with a good increase in ADC was 12.1 months and that for the group with a stable or decreased ADC was 6.67 months, whereas median overall survival was 22.4 and 12.3 months, respectively.

In addition, Chang et al. [31] reported that DWI by 3 T MRI systems may have the potential to monitor early response of lung cancer to chemoradiation through appearance of the early changes in ADC.

**Conclusion**

Contribution of MRI in lung cancer staging provides additional information for accurate cancer patient management that could be crucial in some clinical scenario.

Without any need for ionizing radiation exposure morphological and functional MRI can be used with high levels of accuracy for TNM-stage assessment and follow-up in patients with NSCLC comparable with 18F-FDG PET/CT.

Major advances in the Whole body MRI in the initial evaluation and follow-up of patients with lung cancer have been performed in recent years. Data comparing Whole body MRI and 18F-FDG PET-CT are rare. Therefore, multicentric studies using different magnet systems are necessary to confirm these promising results.

**Take-home messages**

- MRI has superior soft tissue contrast comparing to CT.
- MRI provides morphologic and functional data with diffusion-weighted and perfusion sequences.
- MRI is currently recommended in the assessment of lung cancer extension to the chest wall and the mediastinum as a pre-surgical evaluation.
- Dynamic cine MRI for the detection of chest wall invasion is very accurate.
- DWI has a high specificity for N staging of non-small cell lung cancer (NSCLC) compared with 18F-FDG PET/CT.
- Chemical shift MRI is very accurate in the characterization of adrenal lesions (to differentiate between adrenal metastasis an adrenal adenoma).
- MRI with contrast enhancement currently is the procedure of choice for brain metastasis diagnosis and extension.
- There were no difference for the diagnostic value of whole-body MRI including DWI for preoperative staging assessment of NSCLC with that of 18FDG-PET/CT.
- Early ADC changes observed after initial chemotherapy reportedly correlated with the final tumor size reduction.

**Clinical case**

A 65-year-old patient, with a history of cutaneous Lymphoma, presents a left lower lobe nodule with mediastinal lymph nodes.
Question

The physician question was if the lesion within the thoracic cavity is the same than that on the skin? Two series of images are presented (Figs. 6 and 7). What is your answer to the question?

Answer

The value of the ADC in lymphoma ($0.8 \times 10^{-3} \text{ mm}^2/s$) with a known histology is lower, less than half of the pulmonary nodule ($2 \times 10^{-3} \text{ mm}^2/s$) and that of mediastinal lymph nodes ($1.9 \times 10^{-3} \text{ mm}^2/s$). This difference of ADC value justifies with a good value of confidence that the two tissues are different leading to request a histologic proof of intra thoracic lesions.

The biopsy of mediastinal lymph nodes showed lung cancer, an adenocarcinoma subtype.

Figure 6. Axial Diffusion-weighted image of the skin lesion (a). Axial apparent diffusion coefficient (ADC) map image of the skin lesion (b).

Figure 7. Axial T2-weighted image of the lung and mediastinal lesions (a). Axial ADC map image of the lung and mediastinal lesions (b).

Disclosure of interest

The authors declare that they have no competing interest.

References


