PICTORIAL REVIEW

MRI in lung cancer: a pictorial essay

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ABSTRACT. Imaging studies play a critical role in the diagnosis and staging of lung cancer. CT and 18-fluorodeoxyglucose positron emission tomography CT (PET/CT) are widely and routinely used for staging and assessment of treatment response. Many radiologists still use MRI only for the assessment of superior sulcus tumours, and in cases where invasion of the spinal cord canal is suspected. MRI can detect and stage lung cancer, and this method could be an excellent alternative to CT or PET/CT in the investigation of lung malignancies and other diseases. This pictorial essay discusses the use of MRI in the investigation of lung cancer.

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The current guidelines from the Royal College of Radiologists recommend CT and 18-fluorodeoxyglucose positron emission tomography CT (18FDG PET-CT) for the investigation of every lung cancer patient who is a candidate for radical treatment [1]. For lung cancer, radiologists still only consider superior sulcus tumour (Pancoast's tumour) and assessment of possible invasion of the spinal cord canal as indications for chest MRI. Despite major advances in MRI techniques, these indications have not changed significantly since 1991 [2]. The lung remains a challenge for MRI, but this method provides excellent tissue differentiation, and new sequences have increased the temporal resolution [3], expanding the use of MRI beyond its traditional applications. MRI can currently be used for establishing tumour node metastasis (TNM) staging, lung cancer screening and assessing lung nodules for likelihood of being benign or malignant [3]. This pictorial essay discusses the use of MRI in the diagnosis and staging of lung cancer.

MRI for detection and characterisation of pulmonary nodules

Multidetector CT (MDCT) is routinely used to confirm and characterise lung lesions [1]. It is a very sensitive method for the detection of pulmonary nodules, and is considered the gold standard for detection of these lesions. The sensitivity of MRI for nodules of 5 to 11 mm is between 85% and 95% [4]. Although MDCT can depict nodules as small as 1 or 2 mm, immediate action is recommended only for lesions larger than 7 or 8 mm, depending on the lung cancer risk stratification. Follow-up to assess growth pattern is recommended for

lesions smaller than 7 mm [5]. Koyama et al [6] reported that non-contrast enhanced pulmonary MRI can effectively detect malignant nodules as thin-section MDCT (Figure 1). The overall detection rate of nodules in each MRI sequence (82.5%) was significantly lower than that of MDCT (97.0%, $p < 0.05$), however detection rates were not significantly different for malignant nodules ($p > 0.05$) (Figure 2).

Establishing clinical TNM stage

The overall agreement of clinical TNM (cTNM) staging established by CT compared with post-operative pathological TNM (pTNM) is not significantly better than 50%. Obviously, this comparison does not take into account cases in which the cTNM contraindicates surgery, as it does for the majority of cases. CT and PET-CT are currently the modalities recommended for assessing lung cancer if radical treatment (surgery or other therapeutic modality with curative intent) is suggested [1]. However, the capabilities of MRI have not yet been properly explored.

MRI assessment of T-classification

The T-stage of a tumour is the primary determinant of its resectability [7]. Evaluation of the primary tumour includes an assessment of its size, and the presence and extent of mediastinal or chest wall involvement. Of particular importance is the distinction between T3 and T4 tumours [7]. The definition of a T3 lesion is based either on its size (larger than 7 cm), on the invasion of the chest wall (Figure 3) or the presence of total lung collapse or main bronchus invasion without involvement of the tracheal carina [8]. A lung cancer staged as a T3 is potentially resectable. In contrast, T4 tumours are considered irresectable because of invasion of the

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Figure 1. (a) Axial CT scan showing one pulmonary nodule with lobular margins in the left lower lobe. (b) Axial post-contrast T_1 weighted image showing homogeneous enhancement of the nodule. (c) T_2 weighted image at the same level as the CT scan showing high signal in the lesion. The final diagnosis of this nodule was non-small cell lung cancer.

mediastinum, great vessels, heart, spine brachial plexus proximal to C7 or tracheal carina. When invasion is unclear by CT criteria, MRI can play an important role in defining lesser degrees of "invasion" [7]. MRI is superior to CT for the visualisation of the pericardium, the heart and mediastinal vessels (Figure 4) [9]. MRI can be of use specifically for assessing invasion of the superior vena cava or myocardium, or extension of the tumour into the left atrium via pulmonary veins [9].

MRI is also better than CT at distinguishing the lung mass from the adjacent atelectasis or consolidation, and can be helpful in distinguishing the mass from areas of consolidation or fibrosis post-radiotherapy [7] (Figure 5).

On T_2 weighted MRI, post-obstructive atelectasis and pneumonitis often show higher signal intensities than the central tumour [7]. Although PET-CT is believed to be more accurate for this purpose, MRI has the advantage of being more universally available and less expensive.

MRI assessment of N-classification

An accurate assessment of lymph nodes in the mediastinum is essential for appropriate treatment selection. Nodes present within the ipsilateral peribronchial region or hilum indicates N1 disease (Figure 6); this does not

Figure 2. (a) Pulmonary nodule diagnosed by biopsy as metastatic disease from a lung cancer after chemotherapy. Note the calcifications inside the nodule, simulating a pulmonary granuloma. (b) Post-contrast axial T_1 weighted image showing lesion heterogeneity, with some areas of enhancement. (c) Axial T_2 weighted image showing high-signal lesion that suggests a viable tumour after chemotherapy.

Figure 3. (a) Axial CT imaging of a Pancoast's tumour in the left lung, with no sign of vertebral invasion. (b) Axial T_2 weighted fat saturation image showing a high-signal tumour in the left lung. White arrows show a lack of vertebral invasion. (c) Post-contrast coronal T_1 weighted image showing invasion of the apical chest wall. (d) Axial T_2 weighted image without signs of invasion in the mediastinal structures (arrowheads).

Figure 4. (a) Axial CT scan demonstrating tumour contact with the right atrium and no sign of invasion. (b) Axial T_2 weighted image showing loss of high-signal line (minimal pericardial effusion) between the tumour and right atrium (white arrows), which is a sign of invasion. (c) Coronal T_2 weighted image confirming signs of mediastinum invasion (arrowheads).

change therapeutic decisions. Ipsilateral mediastinal or subcarinal lymphadenopathy constitutes N2 disease (Figure 7), and may be resectable if only a single station N2 disease is involved. Therefore, distinguishing a single station N2 disease from a multiple station N2 disease or an N3 disease is crucial. Pathological contralateral mediastinal, scalene or supraclavicular nodes constitutes N3 disease, which contraindicates radical surgery [7] (Figure 8).

The sensitivity (90.1%) and the accuracy (92.2%) of MRI with short tau inversion-recovery (STIR) turbo spin-echo

(TSE) sequences were significantly better than those of PET-CT (76.7% sensitivity and 83.5% accuracy) [10]. This can probably be explained by the lower sensitivity of PET-CT for nodes smaller than 1 cm [11]. On STIR TSE, metastatic nodes have a high signal, while non-metastatic nodes present with a low signal, which influenced Ohno et al [10] to suggest that MRI should be considered as a substitute for PET-CT for the assessment of mediastinal nodes. Yi et al [12] demonstrated that high signal intensity and eccentric cortical thickening or obliterated fatty hilum

Figure 5. (a) Coronal T_2 weighted image of a lung tumour showing a low signal tumour in the right lung and a high signal atelectasis of right upper lobe caused by massive hilar and mediastinal lymphadenomegaly. Note the clear differentiation between the tumour and atelectasis (arrows). (b) Post-contrast coronal black-blood T_1 weighted image showing the hilar and mediastinal lymphadenomegaly (arrowheads), with significant contrast enhancement, a signal of metastatic disease. (c) Axial T_2 weighted image showing low-signal nodular lesions in the upper lobe atelectasis that suggest secondary implants (black arrow).

(a)

(b)

Figure 6. (a) Axial CT scan demonstrating one lymph node of 8 mm in the right hilum, which is normal based on CT criteria. (b) Axial T_2 weighted fat saturation image showing hypersignal in this lymph node, with obliterated fatty hilum, suggesting metastatic disease. Surgery confirmed metastasis of small cell lung cancer.

on T_2 weighted triple-inversion black-blood TSE on MRI can be reliable indicators of malignancy, even in normal-sized nodes.

MRI assessment of M-classification

PET-CT is currently the modality of choice for completing the pre-operative staging of lung cancer patients. However, in approximately 20% of patients who underwent surgical treatment, PET-CT missed metastases [7]. MRI and PET are reported to have comparable accuracy and efficacy for staging lung cancer patients [13]. Whole-body MRI is better for detecting brain and liver metastases (Figure 9), whereas PET-CT is better for detecting bone and soft-tissue metastases or extrathoracic nodal metastases [7]. PET-CT has a sensitivity and specificity of between 80% and 100% for

adrenal gland metastases, but can yield false-negatives for masses smaller than 1 cm. Chemical-shift MRI can help in distinguishing adrenal gland adenomas by showing reduced signal intensity in opposed phases, with a sensitivity of 100% and a specificity of 81% for adenomas [7]. Enhancement on T_1 weighted images and the absence of fat suppression are indicators of malignancy on adrenal masses. Liver metastases will show as enhancing nodules on T_1 weighted images. MRI has better contrast than PET-CT in the liver, which facilitates the identification of liver lesions [12]. Similarly, a bone lesion showing enhancement on T_1 weighted images should be considered as suspicious for malignancy [12].

The current recommendations suggest that only patients who present with neurological symptoms should be referred for brain CT to investigate brain metastases [1]. Although brain CT is not recommended

(a)

(b)

Figure 7. (a) Axial CT scan showing a 7 mm lymph node in the subcarinal position, with no sign of metastatic spread. (b) Axial T_2 weighted fat saturation image showing a high signal in this lymph node, with obliterated fatty hilum, suggesting metastatic disease. Biopsy confirmed a small cell lung cancer metastasis.

(a)

(b)

Figure 8. (a) Axial T_2 weighted fat saturation image of a patient with lung tumour showing high-signal tumour (arrow). (b) Axial image showing subcarinal and hilar contralateral (arrowheads) lymph node enlargement, representing N2 and N3 disease, respectively.

for lung cancer patients without neurological symptoms, Yi et al [12] suggested that whole body MRI including the head, without a specific brain protocol, can be helpful in detecting occult brain metastases. Other authors have shown a sensitivity of 88% for MRI for brain metastases and a sensitivity of PET-CT as only 24% [14].

Diffusion MRI and lung cancer

Although scanners with integrated MRI with PET are available, the method is likely to remain a research tool for the foreseeable future [15]. However, great developments have been achieved that allow the use of MRI scanners alone for functional and molecular imaging. The functional information provided by MRI is far more

extensive than that provided by dynamic MDCT. Although it does not measure glucose metabolism, MRI is already regarded as capable of providing functional and molecular analysis [15].

Diffusion-weighted imaging (DWI) MRI signals derive from the motion of water molecules in the extracellular, intracellular and intravascular spaces, which allows MRI to better identify neoplastic lesions [7] (Figure 10). Recent studies concluded that lung cancers were easily visualised by DWI, and that differentiating lung cancer from post-obstructive lobar collapse by DWI is feasible [16]. Quantitative analysis of DWI enables differentiation of lymph nodes with and without metastasis [17], and whole-body MRI with DWI can be used for M-stage assessment in lung cancer patients with accuracy as good as that of PET-CT [18] (Figure 11).

(a)

(b)

Figure 9. (a) Axial T_2 weighted fat saturation image of a patient with lung tumour showing high signal metastatic nodules in the lung parenchyma (white arrows). Note the pleural effusion and septal lines that suggest lymphatic carcinomatosis (white arrowheads). (b) Axial T_2 weighted fat saturation image showing various liver high signal metastatic nodules (black arrows), and adrenal metastasis (black arrowheads).

Figure 10. (a) Axial T_1 weighted fat saturation image of a patient with lung tumour showing lung mass and pleural effusion. Note the pleural metastasis (arrow) representing M1A disease. (b,c) Axial diffusion images showing improved lung tumour delineation (arrows) and pleural metastasis (arrowhead).

Conclusion

Although MRI is not currently considered a main imaging modality for the diagnosis and staging of lung cancer, it has some advantages over other imaging modalities, which suggests the use of this method should

be expanded. Limited access to MRI scanners and the limited experience of chest radiologists with the method are probably the major obstacles to incorporating MRI as a routine investigative method for lung cancer patients. MRI can be used in the clinical environment to characterise solitary pulmonary nodules, differentiate

Figure 11. (a) Axial CT scan showing a 7 mm lymph node in the subcarinal position (arrow), with no sign of metastatic spread. (b) Axial T_1 weighted fat saturation image showing enhancement of the lymph node, suggesting metastatic disease. (c) Diffusion-weighted imaging reported a high-signal lymph node that suggested metastatic spread. Biopsy confirmed a small cell lung cancer metastasis.

lung cancer from secondary changes, estimate mediastinal invasion, detect chest wall invasion, assess mediastinal lymph nodes and diagnose distant metastasis.

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