Magnetic resonance imaging in Lung Cancer*

Gordon Gamzu, M.D.†

The role of magnetic resonance imaging (MRI) in the evaluation and staging of lung cancer is being actively investigated, together with its utility in human disease.1,2 Although the number of patients with lung cancer surveyed to date is small, the similar conclusions reached by the different investigators supports their validity.

Basic Principles

Magnetic resonance (MR) is based on the principle that nuclei of elements with an odd number of protons and neutrons spin and behave as magnets. When they are placed in a strong magnetic field, these nuclei align themselves in relation to the field. If radiowaves with a frequency specific to the nucleus and strength of the magnetic field (resonant frequency) is applied, some of the nuclei will absorb the energy of the radiowaves and change the direction of their spins to align against the field. In a fixed magnetic field, as the nuclei spontaneously return to their original direction of spin, they emit radiowaves of the same frequency as the one originally absorbed.1

MRI is achieved by using a nonuniform magnetic field, i.e., with a known gradient, the frequency of the MRI signals emitted will enable them to be localized within the field. The strength of the signal is proportional to the proton density in each location. In most situations present, clinical imaging uses hydrogen nuclei; they are most numerous and thus their signal is strongest.2,3

Two additional properties of the MRI signal, the T₁ and T₂ relaxation times, depend on the local physicochemical environment of the hydrogen nuclei. These factors influence the rate at which nuclei will realign themselves within the magnetic field (T₁) and the rate at which the emitted radiofrequency signal decreases or decays following radiofrequency stimulation (T₂). The T₁ and T₂ magnetic relaxation times vary independently in different tissues and thus affect the intensity of the MR image.3

An MR image is a transformation of the MR intensity (strength of the emitted radiofrequency signal) at different points in the body. In spin-echo images, the pixel intensity at any given point depends on the local hydrogen density, the T₁ and T₂ values of the tissue, bulk movement of protons within the imaging plane, and flow of fluids into or out of the plane. Paramagnetic substances also influence the image intensity. Although the hydrogen density of most soft tissues varies over a range of only 20%, the T₁ and T₂ values can vary by over 500%.

In general, on spin-echo images, fat is the most intense (brightest) tissue, followed by brain and spinal cord, viscera, and muscle, in descending order of intensity.3 Fluid-filled cavities tend to be of variable intensity. Blood vessels containing rapidly flowing blood, bone, and air-filled lung are lowest in intensity.

Technical Considerations

When spin-echo images are obtained, pixel intensity and brightness depend not only on the hydrogen density and T₁ and T₂ values of the tissue studied, but also on 2 parameters of the imager (called TE and TR) that can change the relative contributions of T₁ and T₂ values in the image.3

The TE value (echo time) is measured in milliseconds (<20 to >100) and affects the image intensity relative to the T₂ relaxation time. The TR (repetition time) affects the importance of T₁ in the image. Tissues with a short T₁ value produce an intense signal at all the TR values we use. However, tissues with a long T₁ (such as tumor or some fluids) decrease in relative intensity when a short TR value (0.5 sec) is used, resulting in an increase in contrast with tissue having a shorter T₁ value. Thus, an image using a short TR is said to be "T₁-dependent" or "T₁-weighted." Images with a long TR (2.0 sec or more) have fewer T₁ effects on the image and tissues with short and long T₂ values are similar in intensity.

The MRI techniques that have been used to evaluate bronchogenic carcinoma have varied because of the different machines used.4,5 We consider that imaging should use spin-echo sequences with both short and long TR and TE values. No single imaging sequence can demonstrate the different anatomic areas and abnormalities that should be evaluated in patients with lung cancer.

MRI allows direct imaging in the sagittal and coronal planes with spatial resolution much superior to that of reformatted CT.5,6 In most instances, sagittal or coronal imaging provides no unique information (the transaxial plane is particularly well suited to the evaluation of the hila and most areas of the mediastinum), but it can be of great value in certain situations.5 It allows imaging in the best projection of the trachea and main bronchi, aorta, and vena cavae, and this can sometimes be helpful in diagnosis. Sagittal or coronal imaging can also assist when it is necessary to resolve the edges of structures that lie in or near the transaxial plane, such as the aorticopulmonary window, the diaphragm, around the heart, and at the lung apex. In these locations, imaging in nontransaxial planes can provide diagnostic data unavailable in transaxial MRI or CT. Although MRI provides excellent contrast between different tissues, its spatial resolution in imaging the body is inferior to that of CT. Furthermore, resolution on chest MRI is further degraded by respiratory and cardiac motion. ECG-gating of imaging acquisition improves the resolution of mediastinal and hilar structures, most noticeable in the hilar and mediastinal vessels and inferior mediastinum. This technique does result in an increase in scan time, which limits the number of sequences that can be performed. In the past we did not use ECG-gating for studying patients with lung cancer, but have

*From the Department of Radiology, University of California Medical Center, San Francisco.
†Professor of Radiology.
recently started using it as part of the study for most patients.

Respiratory gating also improves spatial resolution but increases scan times and has not yet come into clinical use.

**STAGING OF LUNG CANCER**

*Lymphadenopathy*

The detection of mediastinal lymph node metastasis is crucial in the staging of lung cancer. On MRI, mediastinal lymph nodes can be distinguished from mediastinal fat because of differences in their $T_1$ values.$^{4,5,11}$ In several studies of mediastinal masses, the $T_1$ value of mediastinal fat (300-350 msec) is always considerably shorter than that for lymph nodes (500-1,500 msec). The contrast between lymphadenopathy and mediastinal fat can be enhanced by using $T_2$-weighted imaging sequence. In some patients, lymph nodes visible with a TR of 0.5 sec are invisible with a longer TR.

In patients with lung cancer, MRI and CT provide similar information in detecting and sizing abnormal mediastinal lymph nodes. However, certain differences do exist. Small (<1 cm) mediastinal lymph nodes seen on CT are not always visible on MR because of its lesser spatial resolution. However, nodes of this size are usually not considered significantly enlarged (even though they can contain occult tumor). Enlarged mediastinal lymph nodes (>1 cm) are sometimes not detected on MR scans performed with low field strength magnets. Occasionally, a group of nodes that are clearly discrete and normal-sized on CT appeared to be a single, larger, abnormal mass on MR because the nodes are summed on MRI. In this instance, a false positive MR diagnosis of lymphadenopathy could result in an unnecessary mediastinal biopsy but would not otherwise effect the clinical approach.

In some patients, MRI can show lymph nodes that are difficult to recognize on CT. This is because of the ease with which vessels and masses can be distinguished on MRI. Similarly, encasement or invasion of mediastinal vessels by a mass can be readily detected on MR.

Whether MR tissue characteristics (such as $T_1$ and $T_2$ relaxation times) can allow for the differentiation of benign from malignant mediastinal lymphadenopathy remains controversial.$^{4,5,12,13}$ Some of our provisional unpublished data suggest that MRI can discriminate between tumor tissue (in the mediastinum) and benign tissues. We can speculate that in the future MRI will enable the distinction between reactive or hyperplastic nodes and malignant nodes.

*Hilar Abnormalities*

Hilar abnormalities are easier to detect on MRI than CT because hilar soft tissue masses and vessels are readily distinguished on MRI.$^{4,5,11,17}$

In patients with bronchogenic carcinoma, MRI can show slight hilar lymph node enlargement impossible to recognize on CT.$^9$ The significance of minimal hilar enlargement with lung cancer is still to be determined. Bronchial abnormalities are less accurately diagnosed using MRI than CT, which again is a function of the lesser spatial resolution of MRI. The significance of hilar abnormality in staging lung cancer must be considered. Hilar node metastases alter the patient’s stage and prognosis, but they do not affect the tumor’s resectability. Patients with a hilar mass can usually be treated by pneumonectomy with expectation of cure.

**Contralateral Parenchymal Lung Disease**

MRI cannot resolve some small lung nodules that are seen on CT, and metastases to the contralateral lung that would make a lung cancer unresectable could be missed with MR. We have observed instances where MRI demonstrated small central lung nodules thought to be blood vessels on CT. However, the remarkable contrast resolution of MRI can discriminate between obstructive pneumonia and atelectasis occurring as a result of bronchial obstruction and the tumor itself. Similarly, we can see instances when MRI distinguished between blood in the lung and tumor.

In such patients, MRI can distinguish the central tumor mass from the distal nonneoplastic lung disease. Such tissue discrimination is not possible with CT or other x-ray-based imaging modalities. This information could prove useful in guiding biopsy or surgical procedures.

**Mediastinal Invasion**

Detection of direct mediastinal invasion by lung cancer is key in staging and determination of resectability. CT can readily detect major degrees of tumor infiltration of the mediastinum but does have difficulty with minor tumor invasion. MRI has the potential for more subtle detection of replacement of mediastinal fat by tumor tissue. The precise accuracy of MRI in determining mediastinal invasion still has to be established and confirmed.

**Pleural and Chest Wall Abnormalities**

Fluids such as pleural fluid usually have long $T_1$ and $T_2$ relaxation times, depending on their water, solute, and protein content. The MRI signal resulting from fluid in the pleural space generally increases in intensity on images having long TR and TE values ("$T_2$-weighted" images).$^{11,12}$ In patients with lung carcinoma and pleural effusion the fluid can be detected using either CT or MRI. Whether the MRI characteristics of pleural fluid will allow the distinction between benign and malignant effusions is still to be determined. In general, chest wall invasion by bronchogenic cancer is difficult to evaluate by CT or MRI. In our experience, the absence of signals from the ribs and the image degradation from respiratory motion causes difficulty with the evaluation of chest wall abnormalities on MRI. In the few cases that we have seen, MRI has not been as accurate as CT in detecting chest wall invasion by lung cancer.

**Abdominal Disease**

Lung cancer commonly metastasizes to the upper abdominal organs, notably the adrenal glands and liver. The evaluation of lung cancer with CT should thus always include the upper abdomen. Because of the length of time required to perform the MRI sequences within the thorax, it is usually not possible to image the upper abdomen using MR. This is a significant potential disadvantage of MRI staging of lung cancer.
CONCLUSIONS

In the evaluation of patients with lung cancer, MRI can detect hilar masses or lymph nodes, distinguish hilar masses and obstructive pneumonia or atelectasis, and demonstrate the relationship of masses to mediastinal vessels. Sagittal and coronal images have been of some advantage. In the diagnosis of mediastinal lymphadenopathy, MRI and CT provide approximately similar results. In some patients, MRI can more easily distinguish mediastinal masses from vessels, while in others it overestimates the size of conglomerate mediastinal nodes. CT is superior in the evaluation of bronchi, pleural, and chest wall abnormality and in the evaluation of the upper abdomen.

However, it must be recognized that the field of MRI is in rapid development. The potential for the technology has not been reached. The intrinsic properties of tissues indicate that MRI does have the potential for tissue characterization, and in the future may be able to determine malignancy within lymph nodes and judge the efficacy of treatment of lung cancer. Further evaluation of this exciting new imaging modality is most definitely warranted.

REFERENCES

1 Pykett IL. NMR imaging in medicine. Sci Am 1982; 246:78-88
13 Webb WR, Gamsu G, Crooks LE. Multisection sagittal and coronal magnetic resonance imaging of the mediastinum and hila. Radiology 1984; 150:475-78