MR Imaging of Lung Cancer: Current state of the art

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ACR Appropriateness Criteria® for Lung Cancer Staging

- NSCLC staging (0-9 scale)
  - CT chest with contrast (9)
  - PET/CT (9)
- MRI for suspected tumor invasion
  - Chest MRI with and without contrast (3)

Why MRI?

Problem solving tool prior to surgery:
- Staging CNS
- Staging body parts that move
- Functional imaging

Therapy monitoring:
- Treatment Response
  - $K_{\text{trans}}$ pre/post xRT/CTX

Educational Goals

1. MRI of the Solitary Pulmonary nodule
2. Site specific application of MR sequences for the staging of NSCLC
3. Functional MRI
4. CT/PET vs MRI or MRI/PET in staging of NSCLC

Efficacy of MRI for detection of solitary pulmonary nodules in a high-risk population: CT as Gold Standard

<table>
<thead>
<tr>
<th></th>
<th>CNR T1w VIBE</th>
<th>CNR T2w HASTE</th>
<th>CNR b-SSFP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Malignant</td>
<td>50</td>
<td>85</td>
<td>30</td>
</tr>
<tr>
<td>Benign</td>
<td>50</td>
<td>58</td>
<td>30</td>
</tr>
<tr>
<td>p value</td>
<td>N.S.</td>
<td>0.002</td>
<td>N.S.</td>
</tr>
</tbody>
</table>

Adapted from Figure 3

CT/PET is the gold standard for NSCLC staging, why should I even bother with MRI?

(Time to go to sleep)
"Lung Cancer is all wet"

<table>
<thead>
<tr>
<th>CNR T2w HASTE</th>
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<tbody>
<tr>
<td>Malignant 85</td>
</tr>
<tr>
<td>Benign 58</td>
</tr>
<tr>
<td>P value 0.002</td>
</tr>
</tbody>
</table>

More protons packed together in a dense Cellular matrix causes a Higher T2w Signal than benign disease

Sommer G, Tromper J, Koenigkam-Santos M, et al. Lung nodule detection in a high-risk population: Comparison of magnetic resonance imaging and low-dose computed tomography. European Journal of Radiology 2013 (e pub) Adapted from Figure 3

MRI of Lung Nodules

Lower sensitivity than CT but has significantly fewer false positives

"... if it can be substantiated that MRI has a Sensitivity of > 75% and Specificity of > 90% for finding malignant SPN, then MRI has the potential to replace LDCT as the primary Lung cancer screening modality."


DCE MRI and DWI of SPN

<table>
<thead>
<tr>
<th>Publication</th>
<th>DCE MRI</th>
<th>DCE + DWI MRI</th>
<th>CT+PET</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensitivity</td>
<td>100%</td>
<td>95% (38/40)</td>
<td>93%</td>
</tr>
<tr>
<td>Specificity</td>
<td>85%</td>
<td>79% (32/41)</td>
<td>78%</td>
</tr>
<tr>
<td>PPV</td>
<td>89%</td>
<td>80% (37/46)</td>
<td></td>
</tr>
<tr>
<td>NPV</td>
<td>100%</td>
<td>85% (11/13)</td>
<td>63%</td>
</tr>
<tr>
<td>Accuracy</td>
<td>87%</td>
<td>91% (40/45)</td>
<td>78%</td>
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MRI vs CT for Malignant SPN

<table>
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</tr>
</thead>
<tbody>
<tr>
<td>Sensitivity</td>
<td>100%</td>
<td>93% (39/39)</td>
<td>93%</td>
</tr>
<tr>
<td>Specificity</td>
<td>66%</td>
<td>36% (10/41)</td>
<td></td>
</tr>
<tr>
<td>PPV</td>
<td>89%</td>
<td>80% (37/46)</td>
<td></td>
</tr>
<tr>
<td>NPV</td>
<td>100%</td>
<td>63% (5/8)</td>
<td></td>
</tr>
<tr>
<td>Accuracy</td>
<td>87%</td>
<td>91% (40/45)</td>
<td>78%</td>
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</tbody>
</table>


Educational Goals

Review MR sequences for the staging of NSCLC

A. Chest wall invasion
B. Spine and brachial plexus involvement
C. Pericardial and great vessel invasion
D. Mediastinal lymph node involvement
E. Heart and pericardium

MRI contributions to TNM: T

- Detection of nodules
  - CT remains reference standard
- Evaluation of invasion
  - Chest wall
  - Spine
  - Heart and great vessels

<table>
<thead>
<tr>
<th>Stage</th>
<th>Relevant Structures</th>
</tr>
</thead>
<tbody>
<tr>
<td>T2</td>
<td>Mainstem bronchus &gt; 2 cm from carina, visceral pleura</td>
</tr>
<tr>
<td>T3</td>
<td>Mainstem bronchus &lt; 2 cm from carina (not carinal)</td>
</tr>
<tr>
<td>T4</td>
<td>Heart, great vessels, carina, esophagus, trachea, spine</td>
</tr>
</tbody>
</table>

DCE MRI and DWI of SPN

Sensitivity 100% (39/39) 95% (38/40) 93% (37/40)
Specificity 85% (32/38) 79% (32/41) 78% (37/46)
PPV 89% (37/40) 80% (37/46)        
NPV 100% (11/11) 85% (11/13) 63% (5/8)
Accuracy 87% (45/54) 91% (40/45) 78% (42/54)
Not all T3 disease is the same

<table>
<thead>
<tr>
<th>Total N=294</th>
<th>5-year survival</th>
<th>P values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mediastinal invasion</td>
<td>39</td>
<td>49.9%</td>
</tr>
<tr>
<td>Chest wall invasion</td>
<td>96</td>
<td>40.7%</td>
</tr>
<tr>
<td>Mass &gt;7 cm</td>
<td>87</td>
<td>32.5%</td>
</tr>
<tr>
<td>2nd NSCLC in same lobe</td>
<td>67</td>
<td>38.4%</td>
</tr>
<tr>
<td>Diaphragm invasion</td>
<td>5</td>
<td>0%</td>
</tr>
</tbody>
</table>


Chest Wall Invasion (T3)

- **Sensitivity 90%**
- **Specificity 86%**
- **Signs of invasion**
  - Extension into chest wall
  - Loss of the extra-pleural fat plane
  - Bone destruction or medullary infiltration

Axial T1 Fat-Sat SE post-contrast image shows direct invasion of the chest wall (gold arrow) and extension of enhancing tissue toward the T3 neural foramen (white arrow).


Goals

Review MR sequences for the staging of NSCLC

- **A. Chest wall invasion**
- **B. Spine and brachial plexus involvement**
- **C. Heart, Pericardial and great vessel invasion**
- **D. Mediastinal lymph node involvement**

Superior Sulcus Tumors: Choice of Pulse sequences

- **Sagittal T1/T2 without fat saturation**
  - ^d soft tissue contrast
  - Nerves and vessels nearly en face
- **Water/Fat separation techniques minimize B0 inhomogeneities**

Superior Sulcus Tumors

Absolute contraindications to surgery

- Involvement of spinal nerves C5-C7
- >50% vertebral body involvement
- Esophageal or tracheal involvement
- N3 or distant metastases

Fat-Sat post-contrast T1 showing right apical mass involving trachea (arrow) and possibly esophagus.


Fat-Sat post-contrast T1 image showing left apical carcinoma invading the chest wall and spine. Enhancement and loss of cortex (arrow).


Fat-Sat post-contrast T1 image showing left apical carcinoma invading the chest wall and spine. Enhancement and loss of cortex (arrow).


Fat-Sat post-contrast T1 image showing left apical carcinoma invading the chest wall and spine. Enhancement and loss of cortex (arrow).


Fat-Sat post-contrast T1 image showing left apical carcinoma invading the chest wall and spine. Enhancement and loss of cortex (arrow).


Fat-Sat post-contrast T1 image showing left apical carcinoma invading the chest wall and spine. Enhancement and loss of cortex (arrow).

Educational Goals

Review MR sequences for the staging of NSCLC
- Chest wall invasion
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- Heart, Pericardial and great vessel invasion
- Mediastinal lymph node involvement

Sequences for assessment of Cardiac Involvement
- Cardiac Gated (CG) CINE balanced steady state free precession (b-SSFP)
- Double/Triple Inversion Recovery
- Soft Tissue Tagging:
  - spatial modulation of magnetization (SPAMM)
- CE MR Angiography

CINE b-SSFP

CINE b-SSFP shows smooth cardiac motion indicating right middle lobe mass not adherent to visceral pericardial surface

Double Inversion Recovery

- Excellent tissue contrast
  - Blood pool – low SI
  - Myocardium – intermediate SI
  - Pericardium – low SI
  - Epicardial and mediastinal fat – high SI

CINE Tagging

- RF pre-pulses selectively null signal in a pattern in the imaging plane
- Motion deforms the initial pattern
- The lack of deformation implies adherence or invasion

Great Vessel Involvement (T4)

Superior to CT in contrast between lung parenchyma, masses and mediastinal fat to evaluate for vessel invasion

Fat Sat Post-contrast T1 shows tumor abutting >50% circumference of the left subcarinal artery (arrows), suspicious for invasion.
**DWI for Lymph Node Assessment**

- DWI has similar accuracy to PET/CT (81% vs. 71%) and better sensitivity on a per node basis (75% vs. 48%)
- Specificity for both modalities 90-95%


**Mesothelioma**

"We conclude that fluorodeoxyglucose (FDG)-PET is superior to MRI and CT but inferior to PET-CT, in terms of diagnostic specificity, sensitivity and staging of MPM."


**Introduction to Functional MRI**

1. Pharmacokinetics of DCE MRI (Toft's equation)
2. Contrast enhancement curves
3. Diffusion Weighted imaging
4. Lobar perfusion

**Toft’s equation**

\[ C(t) = K^{trans} e^{-t_{ep}} \times C_a(t) \]

- \( C(t) \) - Concentration / time curve for tissue of interest
- \( C_a(t) \) - Concentration / time curve for plasma of feeding artery
- \( K^{trans} \) - Extraction fraction of tracer * flow in capillary bed
- \( t_{ep} \) - \( K^{trans} / \text{volume fraction of the extra-cellular space} \)

Schaefer JF, Schneider V, Vollmar J, et al. Solitary pulmonary nodules: association between signal characteristics in dynamic contrast enhanced MRI and tumor angiogenesis. Lung Cancer 2006;53:30-40. (Figure 1)
DCE MRI correlates with decrease in RECIST on CT in NSCLC

Table 2

<table>
<thead>
<tr>
<th>Variable</th>
<th>Before CTX Mean</th>
<th>After CTX Mean</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ktrans</td>
<td>125</td>
<td>77</td>
<td>0.002*</td>
</tr>
<tr>
<td>Kep</td>
<td>1194</td>
<td>871</td>
<td>0.002*</td>
</tr>
<tr>
<td>vaso</td>
<td>171</td>
<td>144</td>
<td>0.12</td>
</tr>
<tr>
<td>Vp</td>
<td>37</td>
<td>25</td>
<td>0.08</td>
</tr>
</tbody>
</table>


Segmental Lung Perfusion analysis prior to lung resection for NSCLC

<table>
<thead>
<tr>
<th>Preparation Test for % lung remaining after planned resection</th>
<th>Correlation coefficient to post op FEV1</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>FEV1, MRI</td>
<td>0.93</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>FEV1, Q</td>
<td>0.89</td>
<td>&lt;0.0001</td>
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Evaluate Effectiveness of Therapy

- MR useful to monitor for local recurrent malignancy, particularly for superior sulcus tumors or those with central canal involvement
- T1 Fat-Sat Post-contrast
- TALM carcinoma treated with surgery and chemoradiation. Mesh reconstruction (arrowhead) and enhancing soft tissue in the right epidural space (arrow), unchanged 6 and 12 months after surgery.

Educational Goals

1. MRI of the Solitary Pulmonary nodule
2. Site specific application of MR sequences for the staging of NSCLC
3. Functional MRI
4. CT/PET vs MRI or MRI/PET in staging of NSCLC

MRI >> CT/PET

- For Brain Mets from Lung Cancer

<table>
<thead>
<tr>
<th>NICE/AH迈片p opioids nts. %MRI+ in 22 pts. Result Using CT MRI as gold Standard</th>
<th>Sensitivity</th>
<th>Specificity</th>
<th>PPV</th>
<th>Accuracy of CT/PET for detection of Brain Mets</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensitivity</td>
<td>27%</td>
<td>98%</td>
<td>75%</td>
<td>83%</td>
</tr>
<tr>
<td>Specificity</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
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CT/PET vs MRI/PET for staging of NSCLC

"On the basis of the results of previous whole-body MRI studies, PET/MRI is expected to show even better performance than PET/CT in M-staging especially for brain and liver metastases."


Summary

- Use of MRI in NSCLC continues to evolve
  - Functional information
    - $K_{\text{trans}}$, DCE enhancement curves, DWI
    - Lobar perfusion prior to resection
    - Treatment response
  - Staging to determine resectability
    - Brain, Chest wall, Spine, brachial plexus, LN, Heart, Pericardium and Great Vessels
- MR/PET offers more for the money

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