Supine Breast MRI with 60-channel Breast Coil

Jessica A McKay-Nault, Ph.D.

Stanford Cancer Imaging Training (SCIT) Seminar / RSL Weekly Seminar

Mentored by Drs. Brian Hargreaves and Bruce Daniel

October 6th, 2021
Breast cancer will kill about 43,600 women in the US in 2021 [American Cancer Society].

MRI screening to detect and treat cancer early:
- MRI screening is expensive and uses contrast agent (safety?)
  - Use DWI to detect cancer
  - DWI suffers from distortion
  - Increase averages
  - Use a coil with better SNR
  - Use parallel imaging and/or Multishot

Prone imaging:
- uncomfortable
- does not associate with geometry of surgery and other imaging
- Use DWI to detect cancer
- DWI suffers from distortion
- Increase averages
- Use a coil with better SNR
- Use parallel imaging and/or Multishot

Supine imaging:
- Respiratory motion
- Breath holds
- Parallel imaging
- Time consuming

Coil for supine breast imaging:
- high channel count
- low g-factor

Problem
Solution
Iteration
Breast cancer will kill about 43,600 women in the US in 2021 [American Cancer Society].

MRI screening to detect and treat cancer early.

Problems:
- MRI screening is expensive and uses contrast agent (safety?)
- Prone imaging: - uncomfortable - does not associate with geometry of surgery and other imaging

Solutions:
- Use DWI to detect cancer
- Use a coil with better SNR
- Use parallel imaging and/or Multishot
- Improve B0 correction
- Use FSE
- Estimate deformation
- Respiratory gating

 coils:
- high channel count
- low g-factor

Awareness and self exams

Supine imaging

Mammogram

DWI suffers from distortion

Respiratory motion

Breath holds

Parallel imaging

Increase averages
Breast cancer will kill about 43,600 women in the US in 2021 [American Cancer Society].

MRI screening to detect and treat cancer early is expensive and uses contrast agents (safety?).

Use DWI to detect cancer. DWI is SNR starved and suffers from distortion.

Use parallel imaging and/or Multishot Prone imaging:
- Uncomfortable
- Does not associate with geometry of surgery and other imaging.

Supine imaging:
- Respiratory motion
- Breath holds
- Increase averages

Use a coil with better SNR.
- High channel count
- Low g-factor

Parallel imaging
- Time consuming
- Parallel imaging
- Fractionation
- Respiratory gating
- New coil
- Estimate deformation

FSE
- Improve B0 correction
- Detour mammogram

Awareness and self exams improve chemotherapy.

Solutions:
- Improved coil design
- Improved techniques
Breast cancer will kill about 43,600 women in the US in 2021 [American Cancer Society]

MRI screening to detect and treat cancer early

MRI screening is expensive and uses contrast agent (safety?)

Prone imaging:
- uncomfortable
- does not associate with geometry of surgery and other imaging

Supine imaging

Use DWI to detect cancer

DWI is SNR starved

DWI suffers from distortion

Use parallel imaging and/or Multishot

Use a coil with better SNR

Increase averages

Time consuming

Parallel imaging

Respiratory motion

Breath holds

Coil for supine breast imaging
- high channel count
- low g-factor

Problem

Solution

Iteration

Iteration
Breast DWI & ADC

- **ADC reflects cell density**: High cell density results in low ADC values, while low cell density results in high ADC values.
- **ADC reflects malignancy**: ADC values are lower in malignant tissues compared to benign tissues.

**Post-contrast T1-weighted**

ADC map

- **Low ADC indicates high cellularity & malignancy**

Clinical applications of DWI for breast cancer:
- **Treatment monitoring**: Increasing ADC values indicate treatment response earlier than conventional measurements.
- **Diagnosis and staging**: Increase specificity and reduce unnecessary biopsies.
- **Screening**: Detection without contrast.

El Khouli, R.H. et al. (2010)
Prone vs Supine Breast Imaging

• Breast MRI is typically acquired prone because of respiratory motion

• However…
  • Supine imaging has better correlation to surgery and other imaging modalities
  • Prone imaging is uncomfortable and awkward
  • Prone coils reduce the effective bore size

• Most supine MRI requires breath holds for high quality images
  • Therefore – we need really really fast imaging!
Breast cancer will kill about 43,600 women in the US in 2021 [American Cancer Society]

MRI screening is expensive and uses contrast agent (safety?)

Use DWI to detect cancer

DWI is SNR starved

Use a coil with better SNR

DWI suffers from distortion

Increase averages

Use parallel imaging and/or Multishot

Use DWI to detect cancer

Time consuming

Parallel imaging

Supine imaging

Supine imaging

Breath holds

Based imaging

Coil for supine breast imaging
- high channel count
- low g-factor

Problem

Solution

Iteration
Challenges

EPI is prone to Distortion
Especially in breast where $\Delta B_0$ can be large.

Phase accrual $\Rightarrow$ geometric shift in PE direction:

$$\Delta y_{PE} = \frac{\Delta f}{BW_{PE}} FOV_{PE}$$

- off resonance (Hz)
- Major sources:
  1. Fat (chemical shift)
  2. $B_0$ inhomogeneity

To reduce $FOV_{PE}$, we need parallel imaging and/or multishot. Therefore, we need reliable sensitivity maps and g-factors.
Challenges

DWI is SNR starved!

Especially at high b-values

MUSE, 2-shot, Air coil with R = 5, Breath hold: 24 second
30 slices, 1.1 mm x 1.4 mm x 5 mm

b = 0 s/mm², 1 NEX

b = 800 s/mm², 4 NEX

DWI is SNR starved!
Especially at high b-values
\[ \text{SNR} \propto \sqrt{N_{\text{ave}} N_{\text{PE}} T_{\text{read}}} \times \delta_x \delta_y \delta_z \times M(\rho, T_1, T_2, B_0, \ldots) \]
Diffusion:

\[ S(b) = S_0 e^{-b*ADC} \]
\[ S(b) = S_0 e^{-b \cdot ADC} \]

Current b-value: \( b_c = 600 \text{ s/mm}^2 \)
Desired b-value: \( b_d = 800 \text{ s/mm}^2 \)
Assume a lesion: \( ADC \approx 1.0 \times 10^{-3} \)

**Same averaging**

\[
\begin{align*}
S_D &= S_0 e^{-800 \times 0.001} \\
S_C &= S_0 e^{-600 \times 0.001} \\
\frac{S_D}{S_C} &= 0.82
\end{align*}
\]

**Same SNR**

\[
\begin{align*}
S_D \sqrt{N_D} &= S_C \sqrt{N_C} \\
S_0 e^{-800 \times 0.001} \sqrt{N_D} &= S_0 e^{-600 \times 0.001} \sqrt{N_C} \\
\frac{\sqrt{N_D}}{\sqrt{N_C}} &= 1.22 \\
\frac{N_D}{N_C} &= 1.5
\end{align*}
\]

\[
\frac{N_b}{N_0} = \left( e^{b \cdot ADC} \right)^2
\]

Lose 20% SNR

Need 1.5x Averages
Breast cancer will kill about 43,600 women in the US in 2021 [American Cancer Society]

MRI screening is expensive and uses contrast agent (safety?)

Prone imaging:
- uncomfortable
- does not associate with geometry of surgery and other imaging

Supine imaging

Use DWI to detect cancer

DWI is SNR starved

DWI suffers from distortion

Respiratory motion

Breath holds

Increase averages

Parallel imaging

Use a coil with better SNR

Use parallel imaging and/or Multishot

Problem

Solution

Iteration

Coil for supine breast imaging
- high channel count
- low g-factor
Motivation for a new coil

The standard breast coil

An option for supine imaging

60-channel breast coil

Problems:
- Only prone imaging

Problems:
- Low channel count in breast region
- Axilla coverage?

High SNR:
- Follows body contour, especially for larger breast size, for close proximity to breast
- High channel count

Axilla coverage
Features:
- 60 elements (30 per half), 7-cm loops
- Heavily overlapped
- Coverage of chest wall and axilla
- Contoured design, up to 40DD
- Can accelerate up to 6x
- Positioning: Supine or Prone (with support)
- Separable halves
Breast cancer will kill about 43,600 women in the US in 2021 [American Cancer Society]

MRI screening is expensive and uses contrast agent (safety?)

- Prone imaging: uncomfortable
- does not associate with geometry of surgery and other imaging

Use DWI to detect cancer

DWI is SNR starved

Use a coil with better SNR

DWI suffers from distortion

Use parallel imaging and/or Multishot

Supine imaging

Respiratory motion

Breath holds

Parallel imaging

Increase averages

Time consuming

Coil for supine breast imaging
- high channel count
- low g-factor

Problem

Solution

Iteration

Preliminary Results

• Compare 60-channel breast prototype coil with 30-channel air coil
Methods

- Phantom Setup
  - Phantom and in vivo volunteer (supine)
  - Fully sampled T1-weighted 3D SPGR data, retrospectively undersampled
  - Pseudo multiple replica method
  - N = 100 iterations
  - Used ESPIRiT to calculate sensitivity maps (BART toolbox)

Acknowledgement: Jeremiah Hess

The geometry factor describes the ability with the used coil configuration to separate pixels superimposed by aliasing. In practice it allows a priori SNR estimates and provides an important criterion for the design of dedicated coil arrays.

\[
\text{SNR}_{\text{Red}} = \frac{\text{SNR}_{\text{full}}}{g\sqrt{R}}
\]
Air Coil

60-channel coil

<table>
<thead>
<tr>
<th>R = 2</th>
<th>R = 3</th>
<th>R = 4</th>
<th>R = 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean: 1.0438</td>
<td>Mean: 1.1615</td>
<td>Mean: 1.5045</td>
<td>Mean: 2.734</td>
</tr>
<tr>
<td>Mean: 1.0079</td>
<td>Mean: 1.0288</td>
<td>Mean: 1.1691</td>
<td>Mean: 2.0353</td>
</tr>
</tbody>
</table>

g-factor

Recon

g-factor

Recon

g-factor

<table>
<thead>
<tr>
<th>g-factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>4</td>
</tr>
<tr>
<td>5</td>
</tr>
</tbody>
</table>
**Air Coil**

Mean: 2.734

![Image of Air Coil]

**60-channel coil**

Mean: 2.0353

![Image of 60-channel coil]
Air Coil

60-channel coil

Mean: 1.0646  
Mean: 1.0126  
Mean: 1.0126  
Mean: 1.0646

Mean: 1.4797  
Mean: 1.1337  
Mean: 1.1337  
Mean: 1.4797

Mean: 2.5097  
Mean: 1.5797  
Mean: 1.5797  
Mean: 2.5097

Mean: 2.4884  
Mean: 2.8291  
Mean: 2.8291  
Mean: 2.4884

R = 2x2  
R = 3x3  
R = 4x4  
R = 6x6
SNR

• Units??

Air Coil

60-channel coil
SNR maps

Air coil

60-channel breast coil
Air Coil

60-channel coil

R = 2
Mean: 1.0062

R = 3
Mean: 1.0187

R = 4
Mean: 1.0478

R = 6
Mean: 1.3561

Recon

g-factor

Mean: 1.0163

Mean: 1.1316

Mean: 1.2986

Mean: 2.2765

Recon

g-factor

Mean: 1.0062

Mean: 1.0187

Mean: 1.0478

Mean: 1.3561

g-factor

0

3
Air Coil

60-channel coil

R = 2x2
Mean: 1.0177

R = 3x3
Mean: 1.1568

R = 4x4
Mean: 1.461

R = 6x6
Mean: 3.7808
DISCO Pre-Contrast

1.2 mm x 1.2 mm x 1 mm, **Acceleration**: 4 x 3, 17 sec breath hold

**Goal**: High spatial and temporal resolution to characterize the contrast uptake of the tumor.
**Single Shot DWI**

Air coil

60-channel breast coil

$b = 50$

$b = 800$
Discussion

• Challenges:
  • Difficult to compare SNR and g-factor maps with the standard breast coil (prone)
  • Would like to compare with InkSpace 24-channel pediatric coil
    • Not included here because it can only be used at 3T3
    • How to compare coils not scanners?
  • ESPIRiT – very sensitive to threshold in phantom case
  • Size of the data!!
Future Work

• Assess in the context of DWI
  • Breath hold or respiratory gated
  • High PI / $N_{\text{shots}}$ to reduce distortion

• Push PI of DISCO protocol and explore spatial/temporal resolution tradeoff for characterizing breast cancer

• Possibly assess the coil in prone position

• Compare the coils in patients
Thank you!

…and others!