Evaluating a Novel Supine Breast Coil for Improved SNR

RSL/SCIT Seminar
July 6th, 2022
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Advised by Dr. Brian Hargreaves and Dr. Bruce Daniel
Mammography

Supine

Prone

Breast Cancer Imaging

MRI

Mammography

Outline

Breast Coils for high SNR
How have you been personally affected by Breast Cancer?

- None - I prefer not to answer
- Fist - I don’t know anyone affected by breast cancer
- 1 - Someone close to me has been diagnosed
- 2 - I personally know of at least one person who has been diagnosed
- 3 - I personally know of several people who have been diagnosed
- 4 - I personally know of many people who have been diagnosed

Breast cancer was expected to kill about 43,600 women in the US in 2021

[American Cancer Society]
How have you been personally affected by Breast Cancer?

<table>
<thead>
<tr>
<th>Number</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>None - I prefer not to answer</td>
</tr>
<tr>
<td>1</td>
<td>Fist - I don't know anyone affected by breast cancer</td>
</tr>
<tr>
<td>2</td>
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</tr>
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<td>3</td>
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</tr>
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</tr>
<tr>
<td>5</td>
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</tr>
</tbody>
</table>
My history

My mom was diagnosed with breast cancer at age 42. According to some guidelines, I am considered “high risk” and recommended to start yearly mammogram and (contrast-enhanced) MRI screening at age 30.

https://pubs.rsna.org/doi/10.1148/radiol.13131669
MRI for Breast Cancer

• Currently requires contrast injection

• Used for staging disease, high-risk screening, and monitoring treatment response

• Typically acquired in the prone position, but recent work is developing supine breast imaging [Moran]

• Significantly more sensitive than mammography, especially for women with dense breasts
  • European Society of Breast Imaging recently changed recommendation to include MRI for women with dense breasts

• There is still controversy over breast cancer screening
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“Prospective trials have shown that annual supplemental MR imaging in conjunction with mammography typically doubles the sensitivity of mammography alone and generally achieves sensitivities greater than 90%”
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<table>
<thead>
<tr>
<th>Study design</th>
<th>Range of estimates of BC overdiagnosis $^{21}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>RCTs*</td>
<td>10% to 22%</td>
</tr>
<tr>
<td>Cohort studies</td>
<td>1.0% to 19.4%</td>
</tr>
<tr>
<td>Ecological studies</td>
<td>1.0% to 76.0%</td>
</tr>
<tr>
<td>Modelling studies</td>
<td>0.3% to 31.9%</td>
</tr>
</tbody>
</table>

"The trade-off between the benefit and the collective harms of BC screening, including false-positives and overdiagnosis, is more finely balanced than initially recognized, however the snapshot of evidence presented on overdiagnosis does not mean that breast screening is worthless. Future efforts should be directed towards (a) ensuring that any changes in the implementation of BC screening optimize the balance between benefit and harms... (b) informing women of all the outcomes that may affect them when they participate in screening... and (c) investing in research that will help define and reduce the ensuing overtreatment of screen-detected BC."
DCIS – Ductal Carcinoma in situ

- Is non-invasive, and the 20-year mortality rate is estimated to be only 3%
- Typically treated with surgery and often radiation
- Probably accounts for a large portion of overtreatment
- A candidate for active surveillance, but...
  - About 25% of patients with DCIS by core biopsy also have invasive disease that is missed in the biopsy
  - We need specificity for very small invasive lesions in a background of DCIS!
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Image: https://www.mypathologyreport.ca/
Our overarching goals

Goal 1: non-contrast MR screening

Goal 2: Characterization of DCIS

Contrast enhanced MRI
- High spatial resolution
- High temporal resolution

Advanced diffusion methods
- High SNR
- Reliable ADC
- High spatial resolution

ADC map
Post-contrast T₁
Goal 1: Non-contrast MR screening

Goal 2: Characterization of DCIS

High-Resolution Breast MRI at 3.0T

Project Number 5R01EB009055-11

Contact PI/Project Leader HARGREAVES, BRIAN ANDREW

...and others!
EPI is prone to **Distortion**

Especially in breast where $\Delta B_0$ can be large.

**Challenges**

**Phase accrual** → geometric shift in PE direction:

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

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

- effective BW in PE direction

To reduce $FOV_{PE}$, we need parallel imaging and/or multishot EPI. 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

$b = 0 \text{s/mm}^2, 1 \text{NEX}$

$b = 800 \text{s/mm}^2, 4 \text{NEX}$
$SNR \propto \sqrt{N_{ave} N_{PE} T_{read}} \ast \delta_x \delta_y \delta_z \ast M(\rho, T_1, T_2, B_0, \ldots)$

$N_{PE} \ast R$

with acceleration
\[ SNR \propto \sqrt{N_{ave} N_{PE} T_{read}} \times \delta_x \delta_y \delta_z \times M(\rho, T_1, T_2, B_0, \ldots) \]

\[ N_{PE} \times R \]

with acceleration

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

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**

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

**Lose 20% SNR**

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

**Need 1.5x Averages**
5 steps to help you squeeze the most SNR from DWI

• Reduce spatial resolution
• Acquire lots of averages – maybe a solution for lesion characterization but not great for fast non-contrast screening (at least in the long run)
• Use a coil with higher SNR
• Go to higher field strength – challenging in breast: not many coil options, sensitive to $B_0$ and $B_1$ inhomogeneity over large FOV
• Use super resolution?
Background: Supine Breast Imaging

+ Established for clinical use
+ Reduced effect of respiratory motion
- Uncomfortable and awkward setup
- Coil reduces the available bore space
- Does not correlate to surgery or other imaging modalities

- Significant effect of respiratory motion
+ Comfortable and easy setup
+ Correlates to surgery or other imaging modalities
Outline

Breast Cancer Imaging

MRI

Prone

Supine

Mammography

Breast Coils for high SNR
Breast Coils

Standard breast coil

- Only prone imaging
- Very uncomfortable and large

An option for supine imaging

+ Flexible and comfortable
- Lower channel count in breast region
- Possible lack of axilla coverage

60-channel breast coil

+ Form fitting to breast for close proximity
+ High channel count
+ Flexible and comfortable
+ Can be used both supine and prone (with support)
Supine LAVA-Flex Protocol in Volunteer

R=3x2, 1 x 1 x 1.6 mm³, 20 sec BH

R=4x3, 0.9 x 0.9 x 1 mm³, 20 sec BH
Patient #1: Late Phase Contrast Enhanced

Standard Clinical DISCO, Prone w/ Sentinelle Breast Coil

LAVA Flex in 20 sec BH, Supine w/ 60-ch Breast Coil
Patient #2: Pre-contrast
1 x 1 x 1 mm³, R = 3x4, Phase Encode A/P w/ Breath Hold

Air Coil

60-ch Breast Coil
Patient #2: Post-contrast

1 x 1 x 1 mm³, R = 3x4, Phase Encode A/P w/ Breath Hold
Volunteer
60-ch Breast Coil: Supine & Prone

- Prone VIBRANT, 1:08 Free Breathing
  \[1 \times 1 \times 2 \text{ mm}^3\]
- Supine LAVA-Flex, 25 sec Breath Hold,
  \[1.1 \times 1.1 \times 1 \text{ mm}^3\]
Patient, Late Phase
16-ch Sentinelle coil and 60-ch Breast Coil: Prone

16-ch Prone DISCO, Free Breathing

60-ch Prone DISCO, Free Breathing
**Goal**

**Purpose:** to apply a simple method to quantitatively compare prone and supine breast SNR distribution using a constant-tissue model and standard SNR measurement approach
Methods: Data

• A 3D T1-weighted SPGR protocol was acquired in the prone and supine position with 2 mm isotropic resolution
  • TR = 3.67 ms, TE = 2.1 ms, flip angle = 12°
  • 3 T Premier (GE Healthcare)
• Deformable saline bag phantoms and 3 healthy volunteers
• The 16-ch Sentinelle coil was used in the prone position; the 60-ch breast prototype coil was used in the supine position
Methods: SNR Measurement

k-space

FFT

Noise

Covariance

Pseudo Multiple Replica Method (includes SENSE)

SNR map

$S_c(x,y)$

ESPIRiT

$N_{Ch}$

$I_{Orig,c}$

$N_{Ch}$
Methods: “Constant” Tissue

k-space

FFT

$S_c(x,y)$

ESPIRiT

$I_{SENSE}$

SENSE

$I_{Mask}$

Mask, scale

Coil weights

$I_{Uniform,c}$

Pseudo Multiple Replica Method (includes SENSE)

SNR map

SNR map

N$_{Ch}$

N$_{Ch}$

$I_{Orig,c}$

Covariance

Noise

$N_{Ch}$

Methods: “Constant” Tissue
Results: Noise Covariance

Prone

Supine

Similar noise levels
Results: SNR in Saline Phantom

Original Image

Constant-Tissue Image

Prone

Supine

Supine True Unfolded

Supine True Folded

Prone True Unfolded

Prone True Folded

Original Image

Constant-Tissue Image
Results: Volunteer (Case 1)
Results: Volunteer

<table>
<thead>
<tr>
<th>Position</th>
<th>Image</th>
<th>Mean</th>
<th>Med</th>
<th>Std</th>
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<td></td>
<td>Uniform</td>
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<td>Supine</td>
<td>Original</td>
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Conclusion

• Robust tools to measure SNR are required for coil development and should be generalizable to various coils and physical positioning of the participant.

• The constant tissue model is an efficient tool to compare SNR across coils in a way that is independent of the tissue composition.

• The 60-channel supine breast coil consistently increased SNR across a phantom experiment and three volunteers. We expect to see a further advantage in the case of parallel imaging.
Other possible ideas

- Use fat as a reference
- Segment fat and water signals to measure average SNR in each individually
- Use ZTE (or other?) to minimize the contrast between water and fat

Next steps

- Compare DWI in the supine position between the Air coil and 60-ch coil
- Validate the “constant tissue” model
- Modify the prone support system
Feedback?

- Pitfalls?
- Other alternatives?
- Ideas for validation?
- Other applications?
Thank you!

...and others!