Internal Breast Tumor Heterogeneity On T2-Weighted Imaging: CUBE vs. DESS

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Outline

• Introduction: T2-weighted breast imaging
• Motivation
• Goals
• Methods
• Results and Discussion
T2-weighted breast imaging: Current

- **T2 Contrast:**
  - Short T2s darker, longer T2s brighter
  - More structured or solid tissues are dark on T2, fluids are bright on T2
- Mostly used for identification of cysts but also can contribute to characterize tumors (morphology, contrast)
T2-weighted breast imaging: Future

- High Correlation of T2-weighted tumor heterogeneity to
  - Response to neoadjuvant chemotherapy\(^1\)
  - survival outcomes\(^2\)
  - histologic grade\(^3\)

- Growing motivation to use MRI for screening, increased interest in “unenhanced” breast MRI protocol (T2 and DWI)

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CUBE (3D Fast Spin Echo)

- Variable flip angle, extended echo train T2-weighted
- High resolution T2-weighted images can be achieved in clinically feasible scan times
DESS (Double Echo Steady State)

- An unbalances steady-state sequence provides T2-contrast at Echo 2.
- More efficient than CUBE.


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DESS (Double Echo Steady State) in the Breast

- Previous study shows strong correlation in lesion-to-tissue signal ratio between qualitative T2-weighted DESS images and T2-weighted CUBE acquisitions.

In this work

• We investigate tumor heterogeneity in 3D CUBE versus DESS T2 weighted sequences.
Methods

To compare the tumor heterogeneity in DESS and CUBE images, DESS, CUBE, and Dynamic Contrast Enhanced (DCE) were acquired in 7 patients with a total of 11 biopsy-proven tumors

1. CUBE: 320 x 320 matrix, 36 cm FOV, 3 mm sl thick, TE 80 ms
2. DESS: 256 x 256 matrix, 36 cm FOV, 3 mm sl thick, TE 15 ms
3. DCE-MRI: 512 x 512 matrix, 27 cm FOV, 1 mm sl thick
Methods cont.

1. Preprocessing: Shading Correction
2. Registration: Single central tumor slice with plenty heterogeneity
3. Tumor localization: Segmentation via Fuzzy C-mean (FCM) algorithm in registered DCE image and mapped to corresponding DESS and registered CUBE images
4. Heterogeneity comparison
5. Evaluation: Entropy and Uniformity
1. Shading Correction

- MR imaging is increasingly performed using arrays of small surface coils
- Advantage: High SNR, parallel imaging
- Disadvantage: B0 and B1 variations, poor image uniformity
- Impede quantitative analysis (i.e., registration and segmentation) that relies on good tissue uniformity
- Vendor methods: post-processing filtration or pre-scanning calibration
- Lack of computational efficiency and require additional calibration scan.
1. Shading Correction

Assumptions:

- The shading field is dominated by low-frequency signals.
- The acquired image, \( v(\vec{r}) \), is equal to the multiplication of the shading field, \( u(\vec{r}) \), and shading-free image, \( I(\vec{r}) \), plus the noise, \( n(\vec{r}) \).
- The noise is handled by simple filtering, smooth model fitting, or some form of regularization and is therefore considered rather irrelevant.

\[
v(\vec{r}) = I(\vec{r}) \cdot u(\vec{r}) + n(\vec{r}),
\]
\[
\log(v(\vec{r})) = \log(I(\vec{r})) + \log(u(\vec{r})) + n(\vec{r}),
\]
1. Shading Correction

- Not only proposed for breast image, but also adapt to other anatomical sites and modality
1. Shading Correction

Sparse Sampling Scheme

- A Fourier Transform based algorithm is used to obtain global non-uniformity estimation from sparse samples of the raw correction map.
- Sparse sampling: \( \Omega_s = \{(i, j) ||S_0(i, j)| < T_H, S_0(i, j) > T_L, \nabla S_0(i, j) < T_g \} \),
- Local Filtration:

\[
\hat{S}_t(i, j) = \frac{\sum_{(s,t) \in \Omega_s} S_0(s, t) \cdot w_\sigma(i-s,j-t)}{\sum_{(s,t) \in \Omega_s} w_\sigma(i-s,j-t)}
\]

\[ \hat{S}_t(i, j) = \frac{(S_0 \cdot f) ** w_\sigma}{f ** w_\sigma} \]

Where,

Gaussian kernel:

\[ w_\sigma(s, t) = e^{-\frac{(s^2+t^2)}{\sigma^2}} \]

Indicator function:

\[ f(i, j) = \begin{cases} 1, & \text{if } (i, j) \in \Omega_s \\ 0, & \text{otherwise} \end{cases} \]
1. Shading Correction

Evaluation Metrics
- Performed on phantom and patient data
- Signal non uniformity (SNU):
  \[ SNU = \bar{\mu}_{\text{max}} - \bar{\mu}_{\text{min}} \]
- Coefficient of variation (CV):
  \[ CV = \frac{\sigma}{\mu} \]
2. Registration

- Via mutual information based similarity registration.
- Gradient descent search method is implemented for optimization.
2. Registration

- Dice overlapping ratio is calculated based on the breast skin-tissue interface (Breast contour):

\[
\text{Dice} = \frac{2|S \cap R|}{|S| + |R|}
\]
3. Tumor localization

DCE Pre

DCE Peak

DCE Subtraction

FCM

Segmented Tumor

Tumor Mapping

Peak-Contrast

Dess

Cube
Heterogeneity comparison for segmented tumor

- Tumor heterogeneity: Entropy and Uniformity

\[
\text{Entropy} = - \sum_{V=0}^{255} p(V) \log_2 p(V) \quad \text{Uniformity} = \sum_{V=0}^{255} [p(V)]^2
\]
Results - Shading correction

Phantom

<table>
<thead>
<tr>
<th></th>
<th>Uncorrected (AU)</th>
<th>Proposed Method (AU)</th>
<th>BCFCM Method (AU)</th>
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<tbody>
<tr>
<td>SNU</td>
<td>243.42</td>
<td>19.25</td>
<td>22.58</td>
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<tr>
<td>CV</td>
<td>0.26</td>
<td>0.020</td>
<td>0.023</td>
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<tr>
<td>Processing time</td>
<td>~2 sec for matrix (512x512x70)</td>
<td>~1.5 min per slice (512x512)</td>
<td></td>
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</tbody>
</table>
Results - Shading correction

Patient data

Patient 1

Uncorrected Image

Corrected Image

Patient 2

Uncorrected Image

Corrected Image

FCM Segmentation
Results - Shading correction

Patient 3

Uncorrected Image  Corrected Image

Patient 4

Uncorrected Image  Corrected Image

FCM Segmentation
## Results - Shading correction

Patient data: quantitative results

<table>
<thead>
<tr>
<th></th>
<th>SNU</th>
<th>CV</th>
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<td>Uncorrected (AU)</td>
<td>Proposed Method(AU)</td>
<td>Uncorrected (AU)</td>
<td>Proposed Method(AU)</td>
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<tr>
<td>Patient 1</td>
<td>216</td>
<td>33</td>
<td>0.26</td>
<td>0.036</td>
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<td>Patient 2</td>
<td>270</td>
<td>30</td>
<td>0.21</td>
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<td>Patient 3</td>
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<td>Patient 4</td>
<td>280</td>
<td>50</td>
<td>0.36</td>
<td>0.068</td>
</tr>
</tbody>
</table>
Results - Other Anatomical Sites

Spine MRI

Pelvis CT

Brain DWI
Result - Registration

• The Dice ratio calculated for DESS versus CUBE and DESS versus DCE for all eight patients are 96.5±3.5% and 98.5±2.1%, respectively, indicating a successful structural registration.
Result – Heterogeneity

Entropy

R = 0.99 (P<0.01)

Uniformity

R = 0.99 (P<0.01)
Result – Heterogeneity
Conclusion and Discussion

• We proposed an shading correction algorithm that removes image inhomogeneity for both phantom and patient images with negligible processing time.

• In 11 tumors, the heterogeneity and spatial distribution of T2 signal highly correlated between DESS and CUBE images, indicating that T2 contrast may not be greatly affected by the difference in echo times between these two methods.

• The results also indicate that DESS may be a viable alternative for T2-weighted acquisitions.

• Future work will include analysis of a much larger number of patients and tumors to determine whether the findings of the initial study are consistent across the wider patient population.
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