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

Linxi Shi, PhD
May 24th, 2018
Department of Radiology
Stanford University

Stanford University

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)

DCE (Peak contrast)

3D-FSE-CUBE

Stanford University
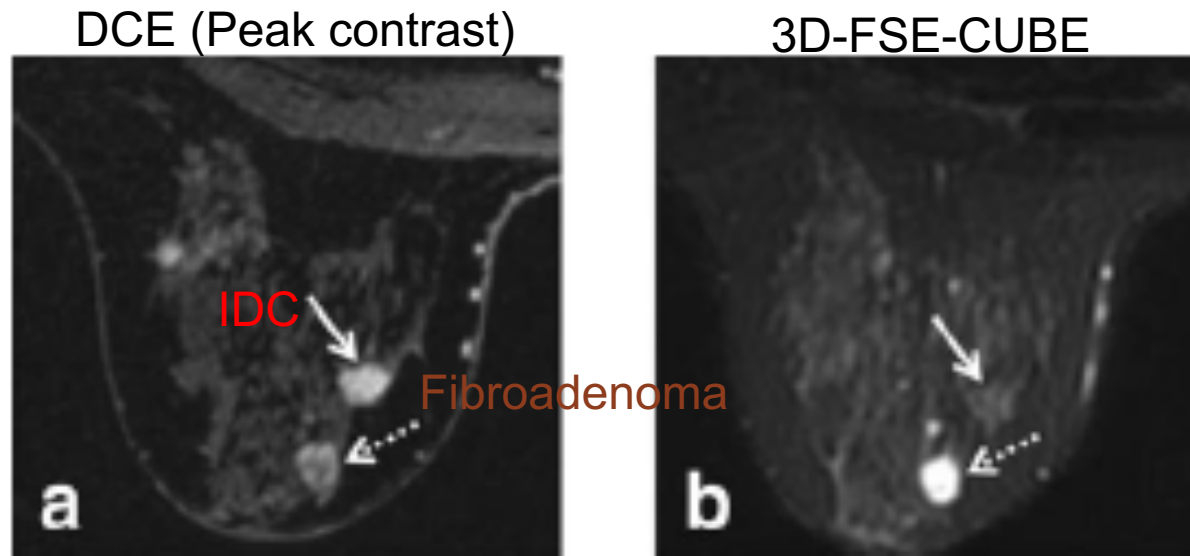
# T2-weighted breast imaging: Future

- **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)**

[1] Parikh, J., et al., Changes in primary breast cancer heterogeneity may augment midtreatment MR imaging assessment of response to neoadjuvant chemotherapy. Radiology, 2014. **272**(1): p. 100-12.

[2] Kim, J.H., et al., Breast Cancer Heterogeneity: MR Imaging Texture Analysis and Survival Outcomes. Radiology, 2017. 282(3): p. 665-675.

[3] Ko, E.S., et al., Assessment of Invasive Breast Cancer Heterogeneity Using Whole-Tumor Magnetic Resonance Imaging Texture Analysis: Correlations With Detailed Pathological Findings. Medicine (Baltimore), 2016. **95**(3): p. e2453.

Stanford University

CUBE (3D Fast Spin Echo)
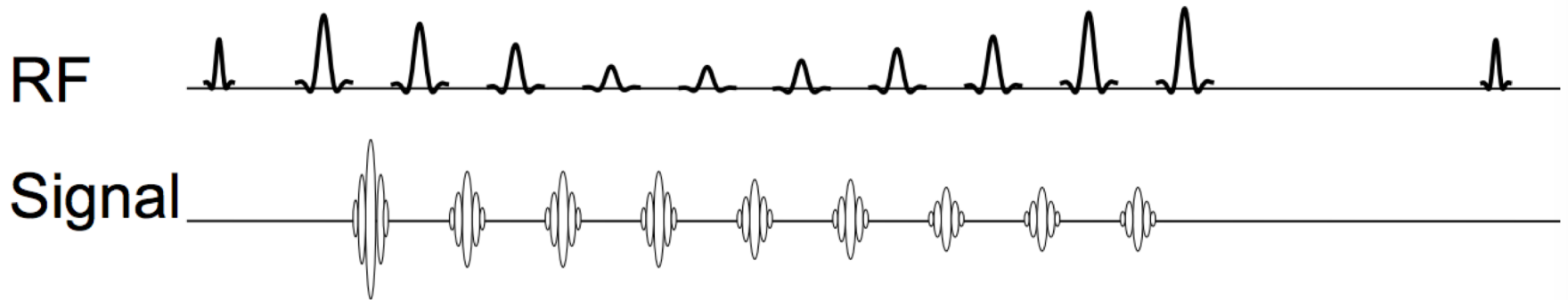
- Variable flip angle, extended echo train T2-weighted
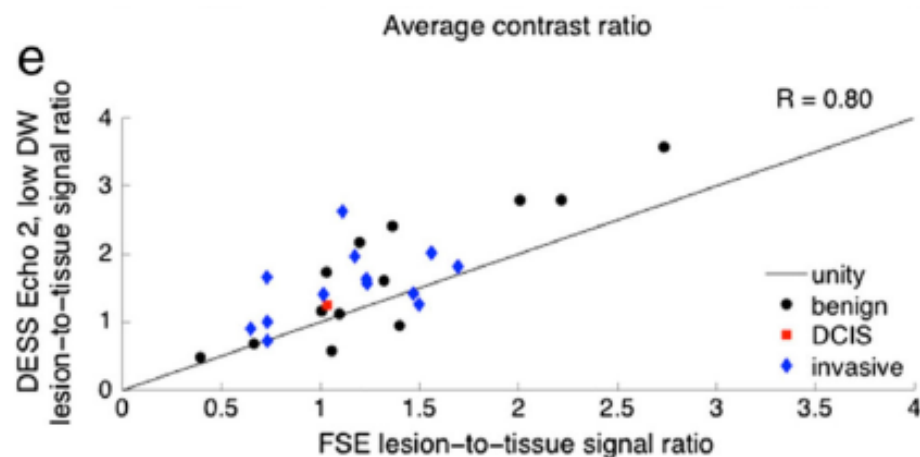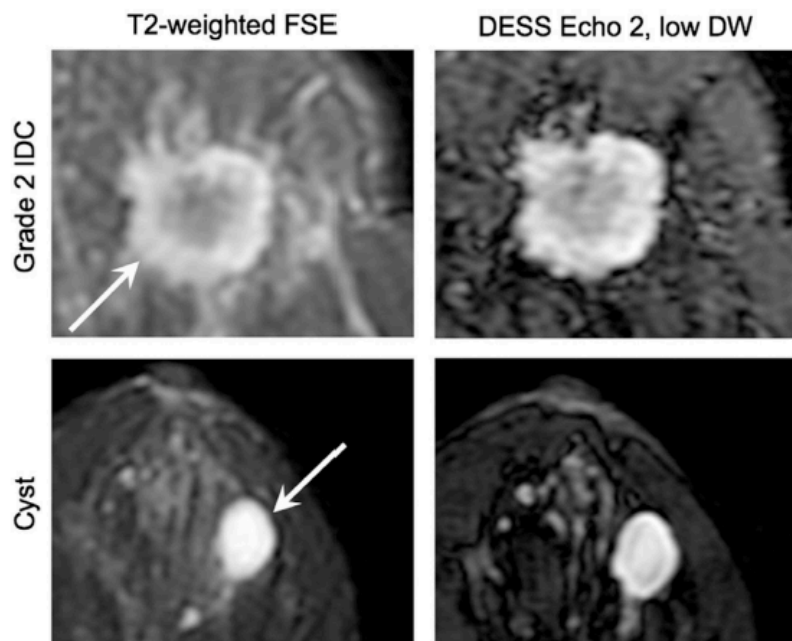- High resolution T2-weighted images can be achieved in clinically feasible scan times

Stanford University

DESS (Double Echo Steady State)
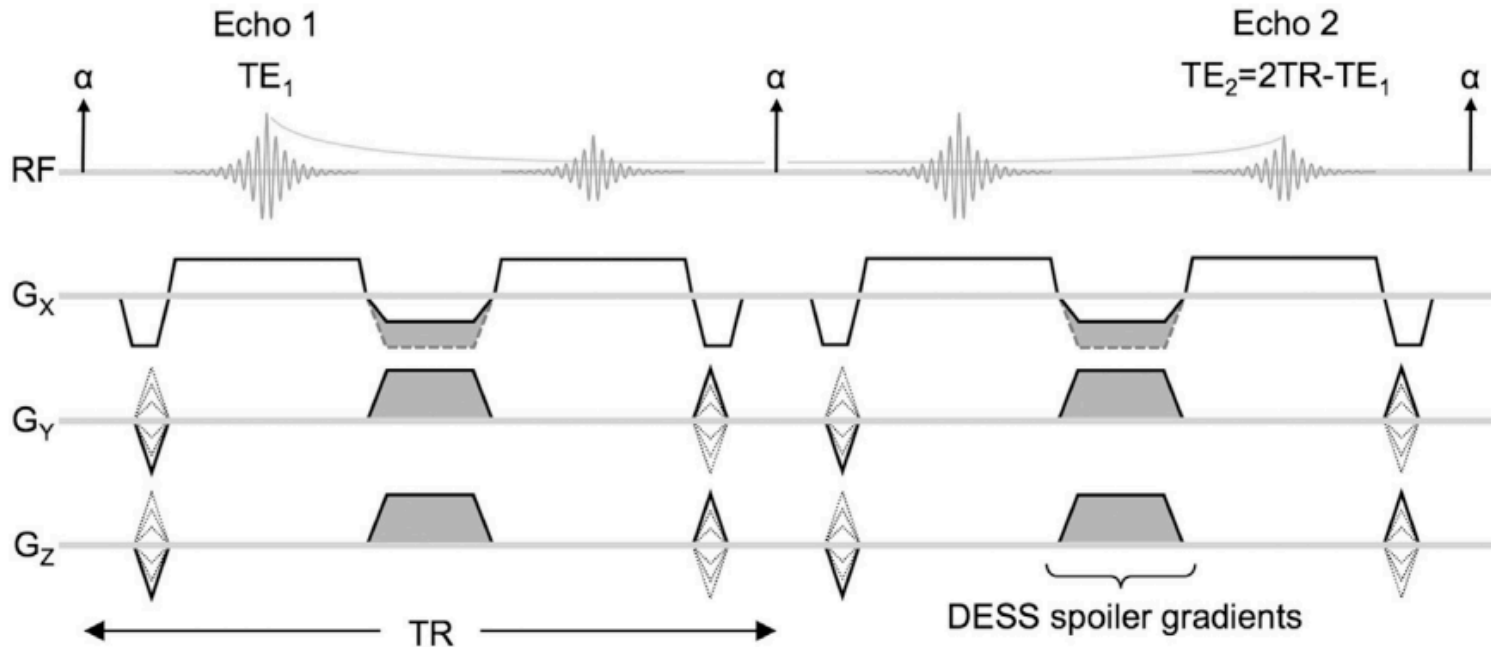
- An unbalances steady-state sequence provides T2-contrast at Echo 2.
- More efficient than CUBE.

*Granlund, et al., MRM **2014, 32(4): 330-341.***

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

Granlund, et al., MRM 2014, 32(4): 330-341.

Stanford University

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 512matrix, 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.
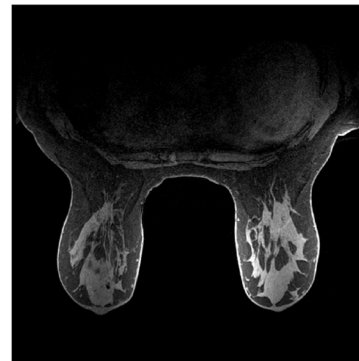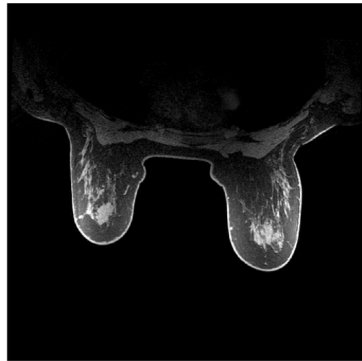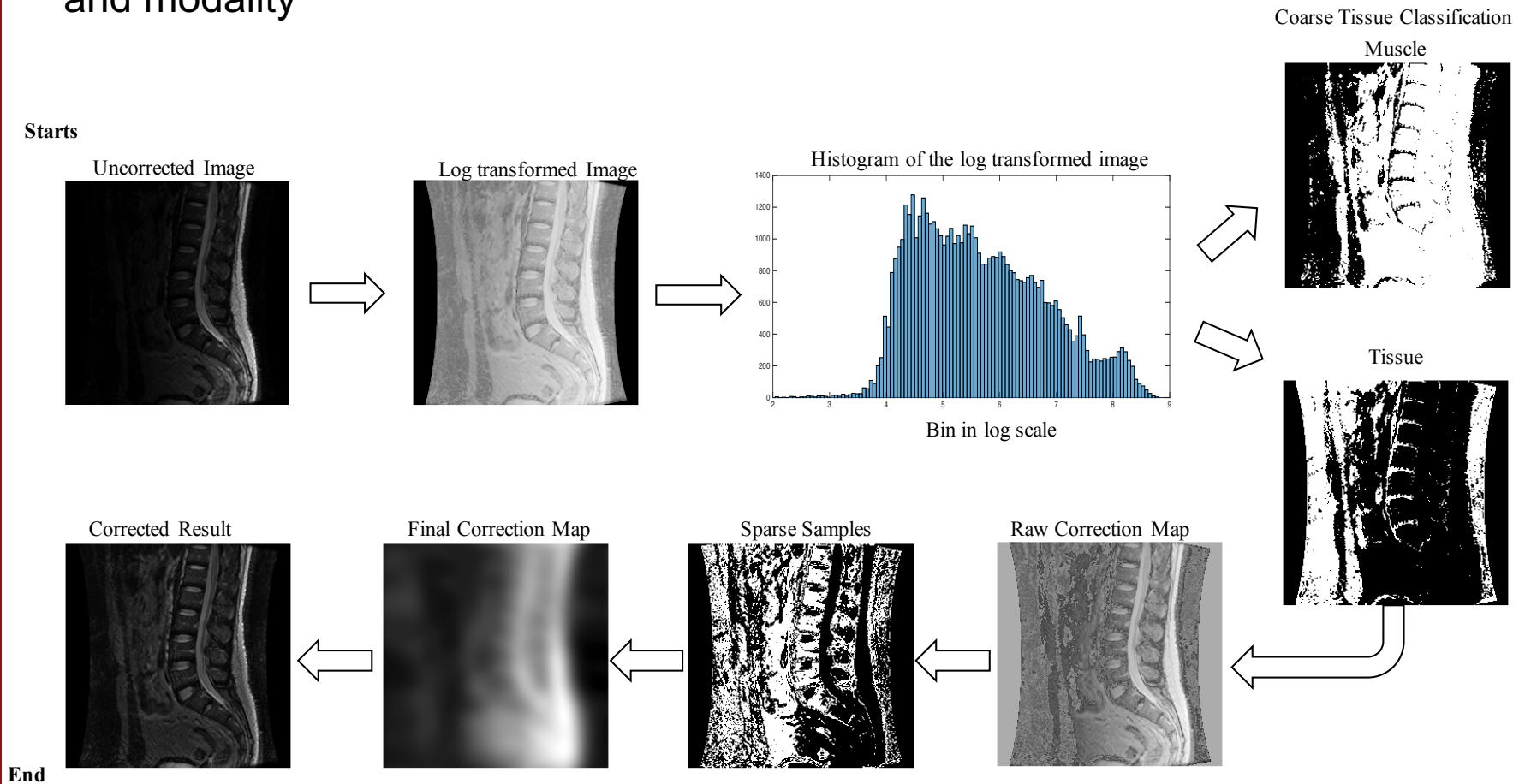
1. Shading Correction

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.

$$v(\vec{r}) = I(\vec{r}) \cdot u(\vec{r}) + \widetilde{n(\vec{r})},$$

$$\log(v(\vec{r})) = \log(I(\vec{r})) + \log(u(\vec{r})) + \widetilde{n(\vec{r})},$$

1. Shading Correction

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

Coarse Tissue Classification

Muscle

Starts

Uncorrected Image

Log transformed Image

Histogram of the log transformed image

Bin in log scale

Tissue

Corrected Result

Final Correction Map

Sparse Samples

Raw Correction Map

End

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:

$$\hat{S}_t(i,j) = \frac{\sum_{(s,t)\in\Omega_s} S_0(s,t)\cdot w_\sigma(i-s,j-t)}{\sum_{(s,t)\in\Omega_s} w_\sigma(i-s,j-t)} \qquad \hat{S}_t(i,j) = \frac{(S_0\cdot f)**w_\sigma}{f**w_\sigma}$$

Where,

Gaussian kernel: $w_\sigma(s,t) = e^{-\frac{(s^2+t^2)}{\sigma^2}}$

Indicator function: $f(i,j) = \begin{cases} 1, & if\ (i,j) \in \Omega_s \\ 0, & otherwise \end{cases}$

1. Shading Correction

Evaluation Metrics

- Performed on phantom and patient data

- Signal non uniformity (SNU):
  - › $SNU = \bar{\mu}_{max} - \bar{\mu}_{min}$

- Coefficient of variation (CV):
  - › $CV = \dfrac{\sigma}{\mu}$

MULTI-MODALITY BREAST BIOPSY AND SONOGRAPHIC TRAINER
MODEL 073
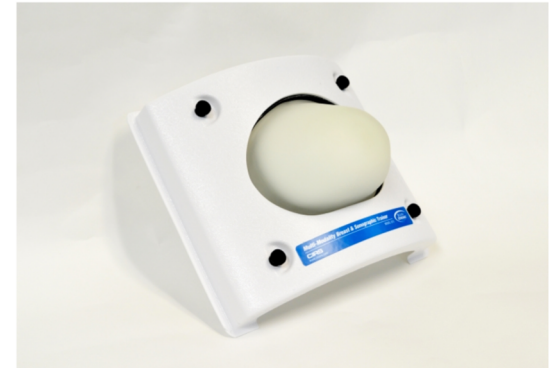
DURABLE TRAINING PHANTOM FOR ULTRASOUND, MAMMOGRAPHY, X-RAY AND MRI
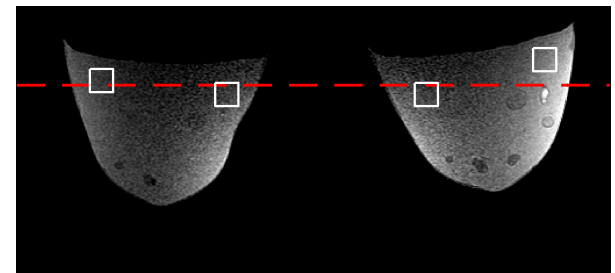
2. Registration

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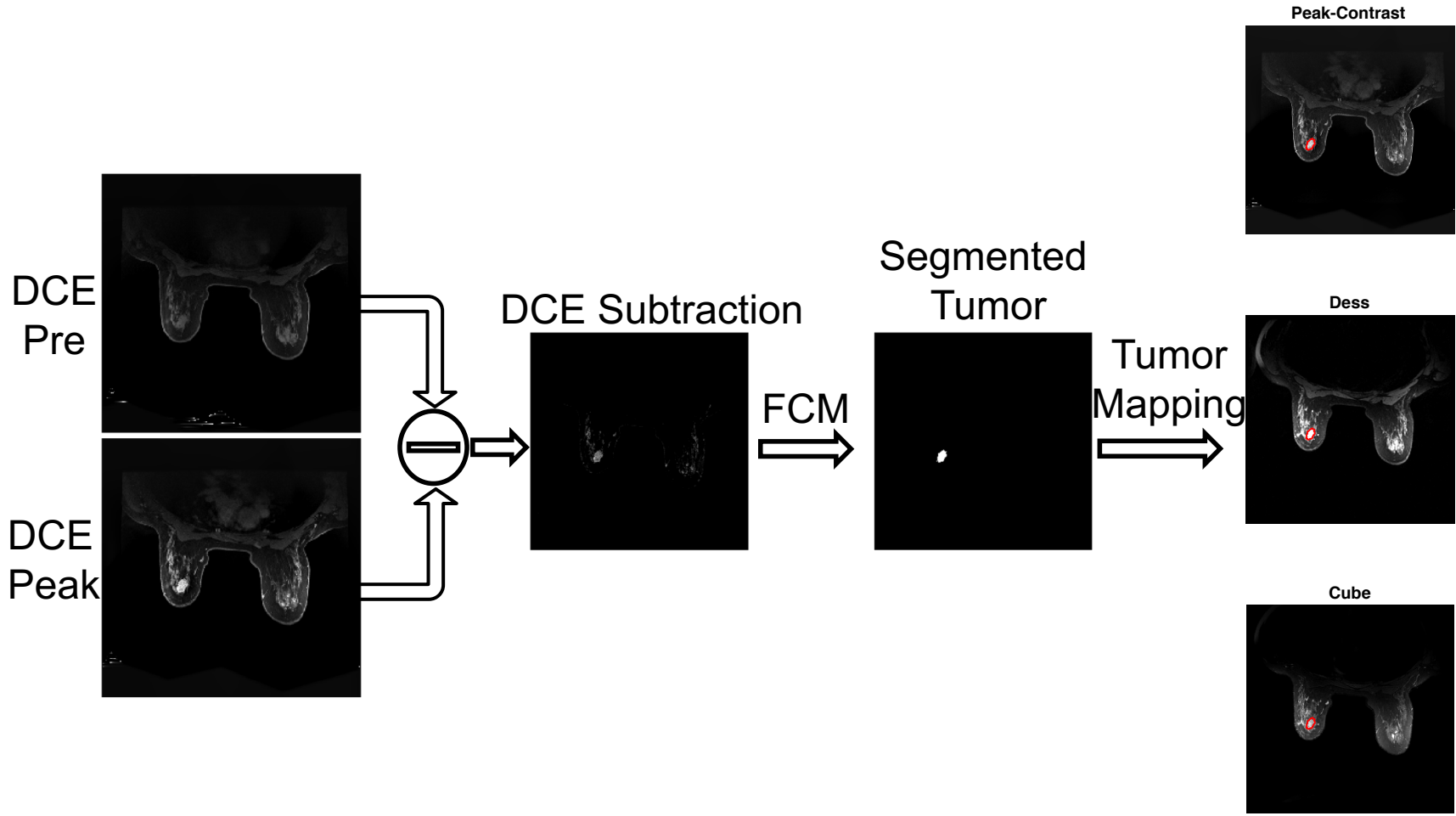- Gradient descent search method is implemented for optimization

DCE (Peak contrast) DESS echo2 CUBE

R

DCE Reg DESS echo2 CUBE Reg

Stanford University
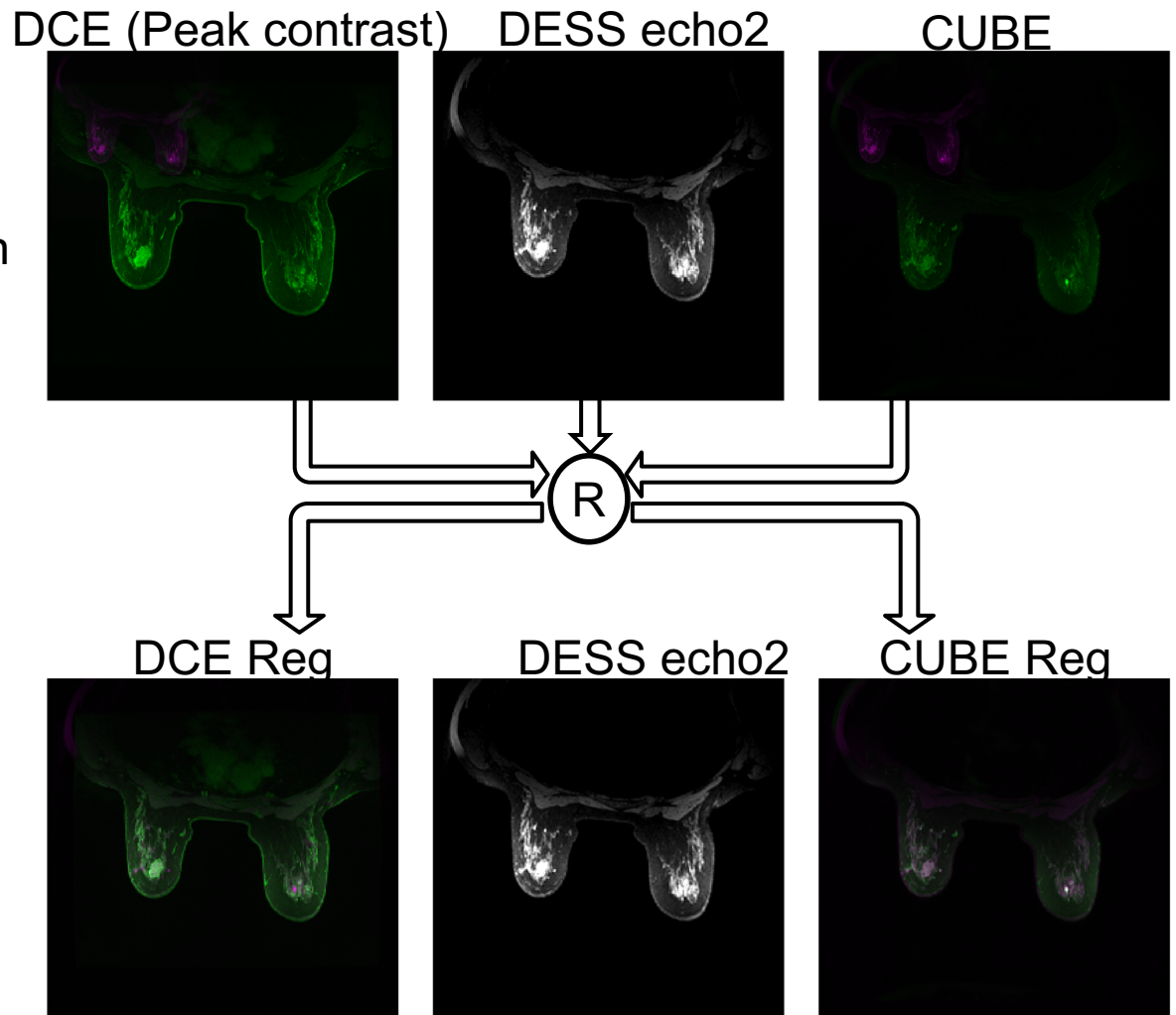
2. Registration

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

$$Dice = {}^{2|S \cap R|}\!\big/\!_{|S|+|R|}$$

3. Tumor localization

Peak-Contrast

DCE Pre

DCE Subtraction

Segmented Tumor

Tumor Mapping

FCM

Dess

Cube

DCE Peak

Stanford University

Heterogeneity comparison for segmented tumor

- Tumor heterogeneity: Entropy and Uniformity

$$Entropy = -\sum_{V=0}^{255} p(V)log_2 p(V) \qquad Uniformity = \sum_{V=0}^{255} [p(V)]^2$$

Deformed DCE subtraction   **DESS**   **CUBE**
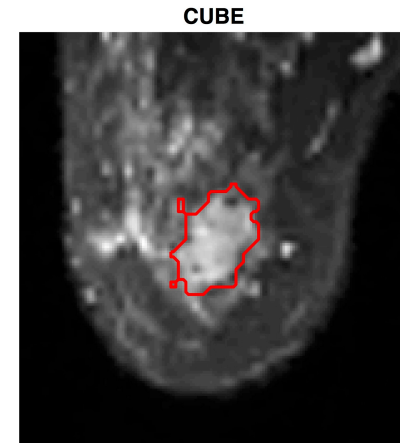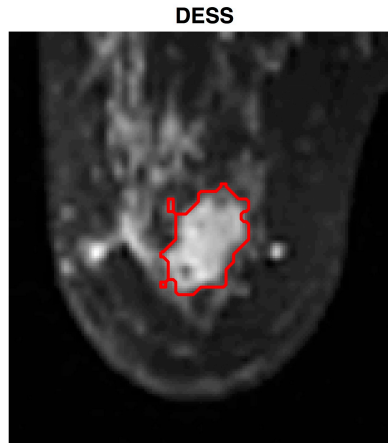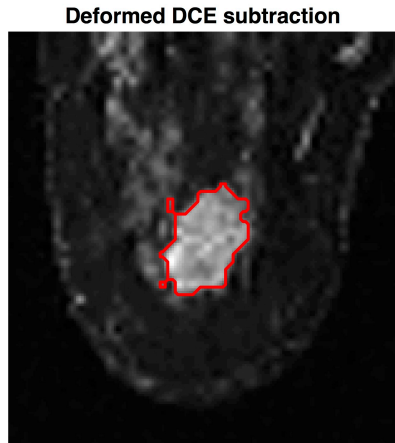
Results -Shading correction

Phantom
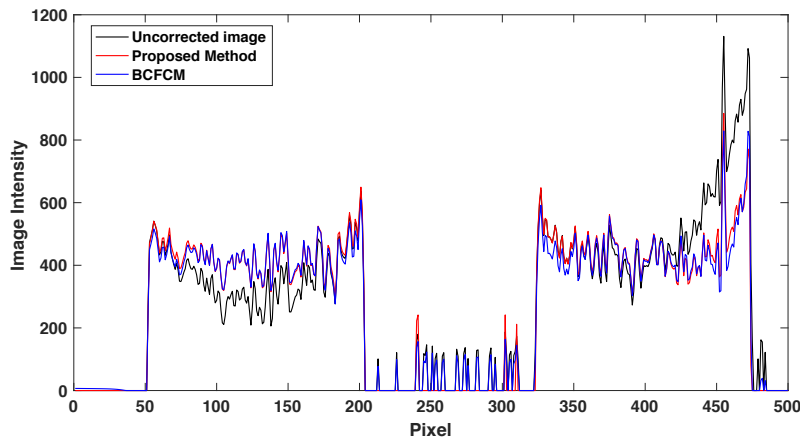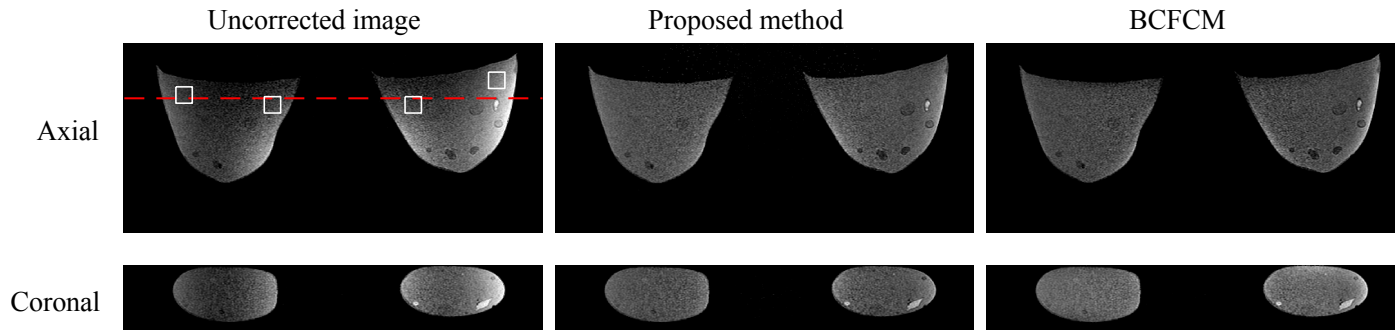
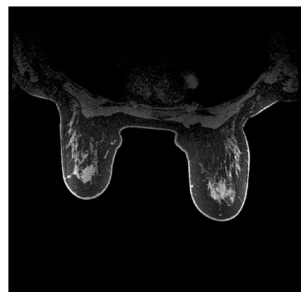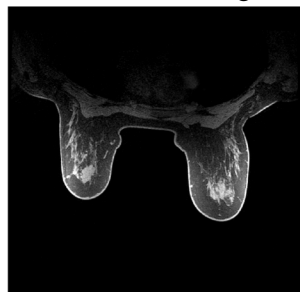|	Uncorrected (AU)	Proposed Method(AU)	BCFCM Method(AU)
SNU	243.42	19.25	22.58
CV	0.26	0.020	0.023
Processing time		~2 sec for matrix (512x512x70)	~1.5 min per slice(512x512)

Results -Shading correction

Patient data

Patient 1 — Uncorrected Image, Corrected Image; Patient 2 — Uncorrected Image, Corrected Image; FCM Segmentation

Results -Shading correction

Patient 3

Patient 4

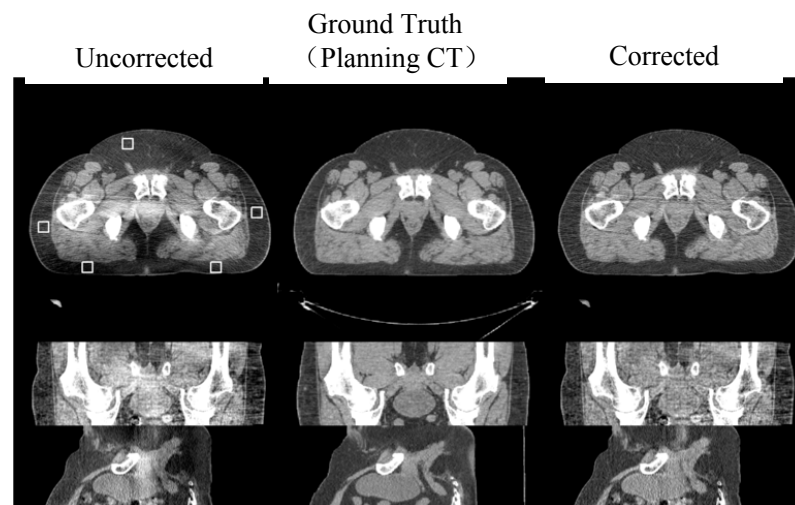Uncorrected Image   Corrected Image   Uncorrected Image   Corrected Image

FCM Segmentation

Stanford University

Results -Shading correction

Patient data: quantitative results

	SNU		CV	
	Uncorrected (AU)	Proposed Method(AU)	Uncorrected (AU)	Proposed Method(AU)
Patient 1	216	33	0.26	0.036
Patient 2	270	30	0.21	0.033
Patient 3	290	54	0.35	0.064
Patient 4	280	50	0.36	0.068

Results-Other Anatomical Sites

Spine MRI

Uncorrected Corrected

Sagittal

Axial

Pelvis CT

Uncorrected | Ground Truth （Planning CT） | Corrected
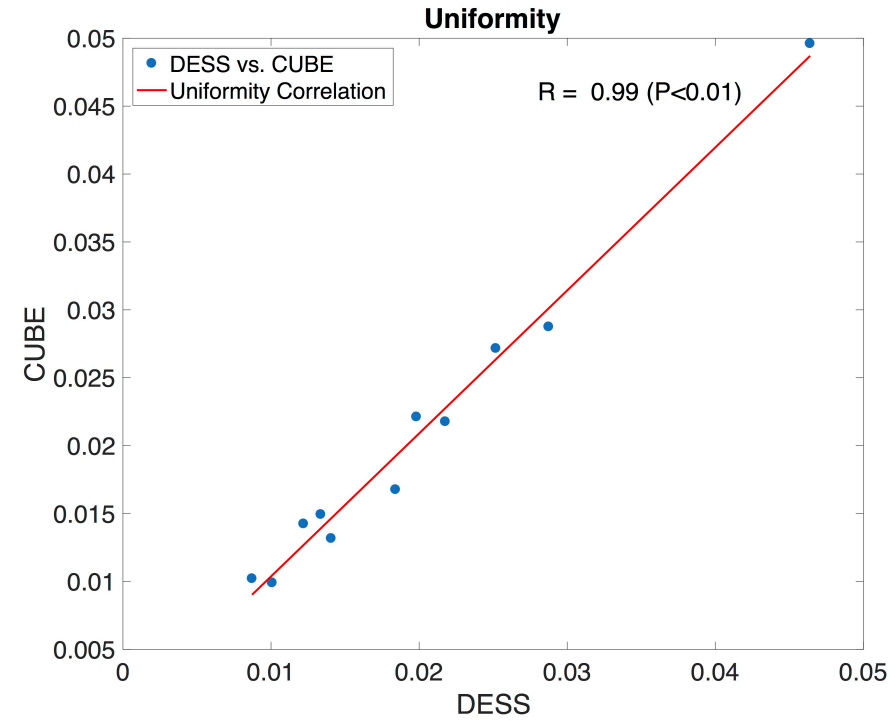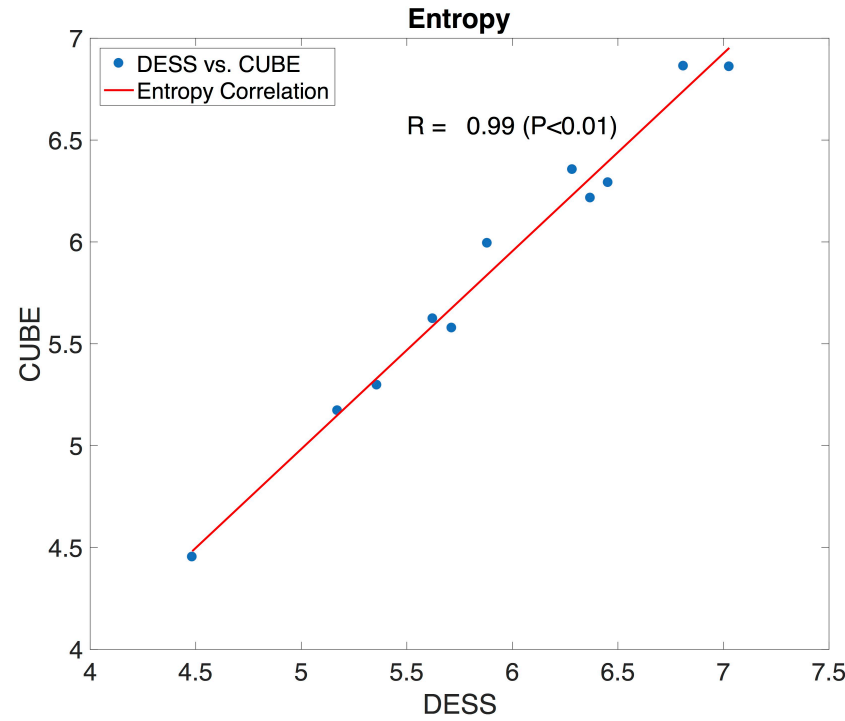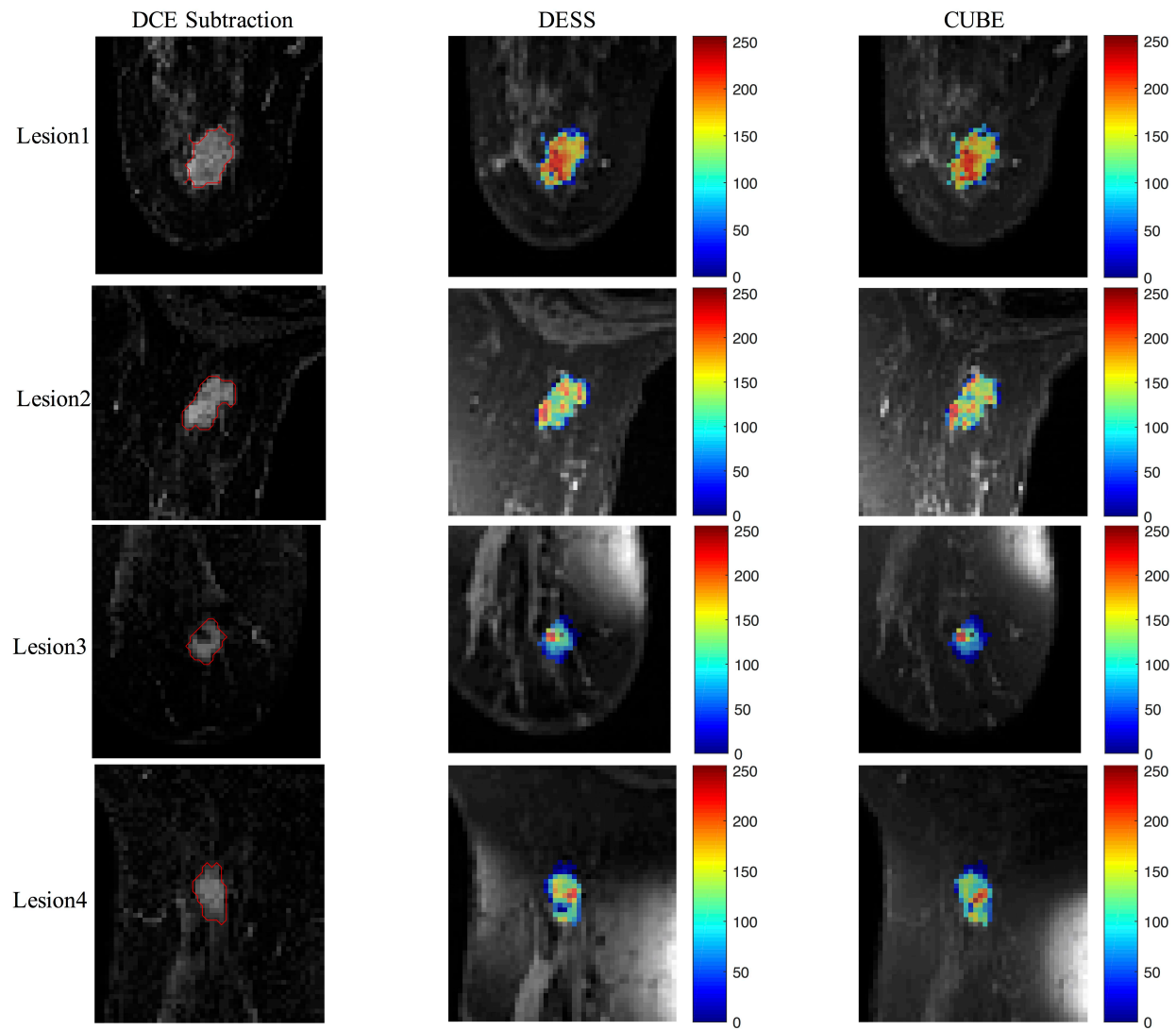
Uncorrected Corrected
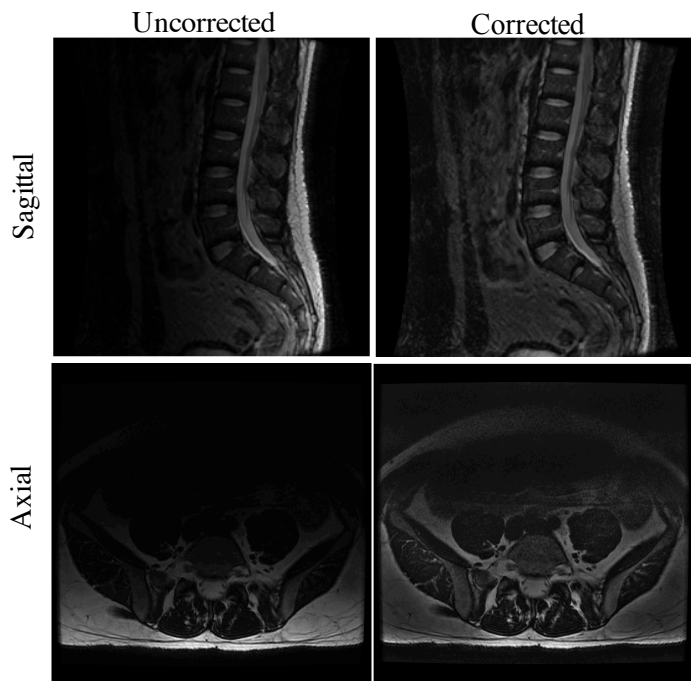
Brain DWI
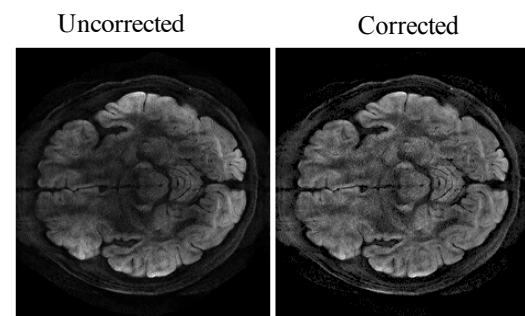
Result - Registration

- The Dice ratio calculated for DESS versus CUBE and DESS versus DCE for all eight patients are $96.5\pm3.5\%$ and $98.5\pm2.1\%$, respectively, indicating a successful structural registration

Result – Heterogeneity

Stanford University

Result – Heterogeneity

Stanford University

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.
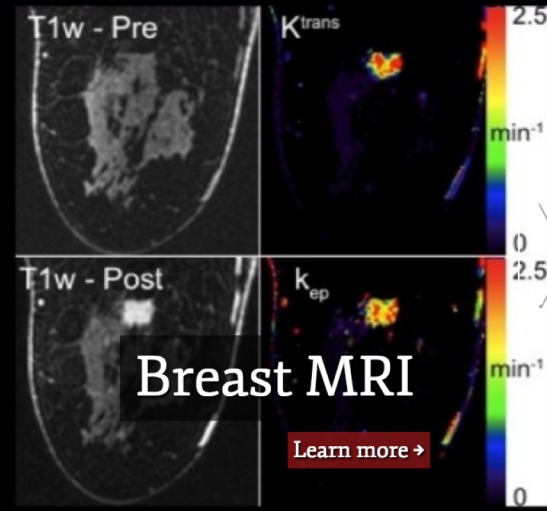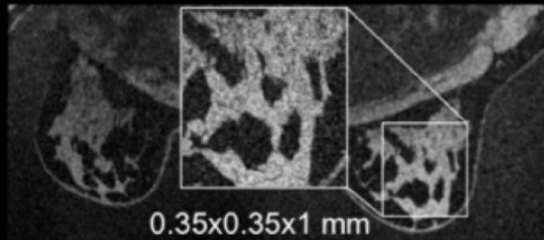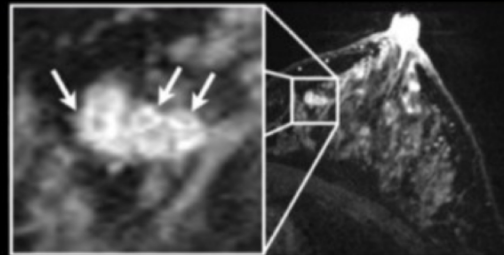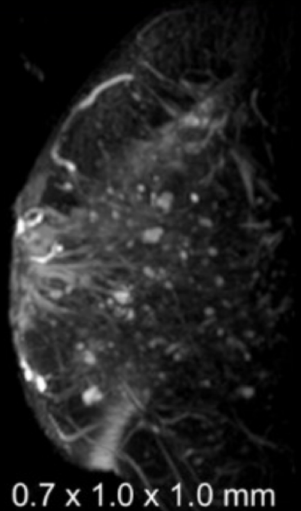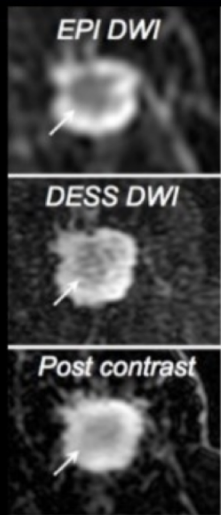
Acknowledgment

Dr. Brian Hargreaves

Dr. Bruce Daniel

Dr. Catherine Moran

Dr. Daehyun Yoon

Steffi Liu Perkins

Yuxin Hu

Thank you!
&
Questions?