Accurate local estimation of compressed breast thickness in digital breast tomosynthesis using an iterative reconstruction approach

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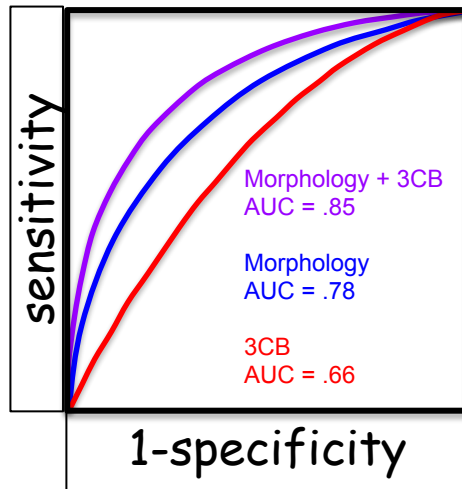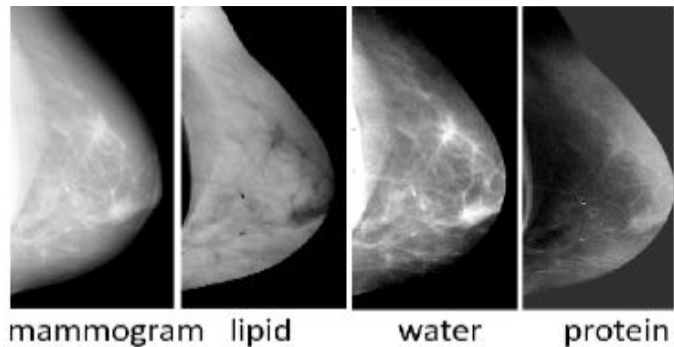
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Importance of breast composition

- Previous works investigated breast composition and how it relates to different lesion types
- Compositional features of breast lesions were shown to be diagnostically significant
- Three compartment brest or 3CB algorithm
  - Concept: Lipid, water, and protein are the three major components of breast tissue
  - Method: Uses dual energy mammography and thickness measurements to derive lipid, water, and protein maps for a given breast
  - Significance: Malignant lesion types have unique compositions when compared to non-malignant types.

mammogram   lipid   water   protein

Morphology + 3CB
AUC = .85

Morphology
AUC = .78

3CB
AUC = .66

sensitivity

1-specificity

Drukker, Med Phys. 2014 Mar; 41(3): 031915.

3CB for full field digital mammography (FFMD)

- Accurate thickness is vital input for the 3CB algorithm
- Prior 3CB work was developed for 2D
- Breast geometry and thickness was derived with the help of a phantom attached to the top of the compression paddle
  - The paddle phantom contains 9 lead bbs (indicated by red arrows)
  - Paddle tilt, warp, and compression is determined from the bbs spatial relation to each other
- Issues with using the paddle phantom:
  - Data needs to be collected prospectively with the phantom attached to the paddle
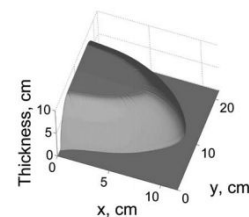 - Requires extra setup and calibration
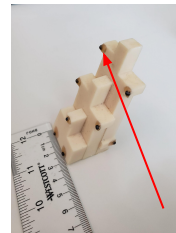
Paddle phantom
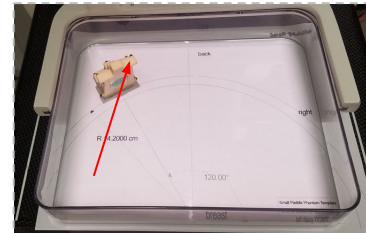
Orientation of phantom on compression paddle
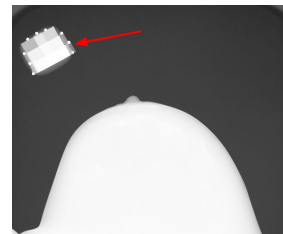
Raw FFDM with paddle phantom


Calculated thickness map

3 compartment breast for tomosynthesis

- **<u>Goal</u>**: Apply the 3CB methods and algorithm to tomosynthesis to create lipid, water, and protein volume fractions
- **<u>Problem</u>**: Tomosynthesis has poor resolution in the z-axis thus making it difficult to get accurate thickness measurements
- **<u>Hypothesis</u>**: Tomosynthesis images contain enough information from which thickness and other geometrical measurements can be derived using sinograms.

Approach with simulation

- We created a virtual breast object for which we can define the cross sectional geometry parameters of a compressed breast
  - Parameters: thickness, width, and warp
- We use Matlab simulation to create simulated sinograms from the virtual breast object we define
- Sinogram - A set of projections under different angles organized in 2D
  - GE's system create 9 projections
  - Each pixel column, from the chest wall to the nipple, is a cross sectional slice and a sinogram can be generated for each
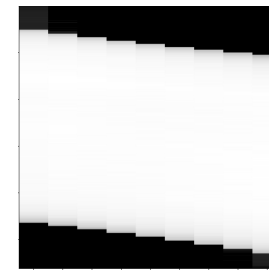

warp(width

thickness (t)   radius (r) = t/2
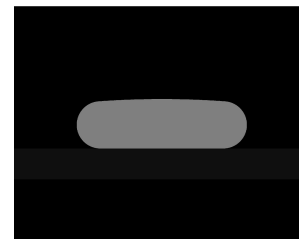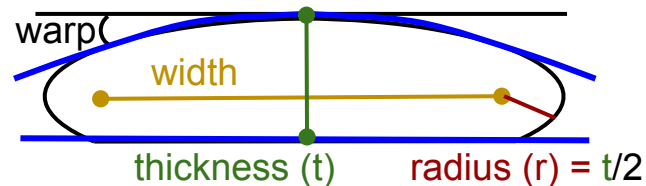
Virtual Breast Object

Simulated sinogram
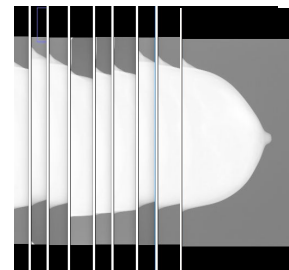
9 projections

Real sinogram

Prediction and modeling approaches

- Method 1: Iterative reconstruction
  - Virtual breast object and its simulated sinogram was generated and compared to the real sinogram until error was minimized
  - Regenerating new breast objects of different parameters (width, thickness, and warp) and its sinograms to match the real sinogram was computationally expensive.
- Method 2: Machine learning
  - Sampled the search space of possible breast parameters to generate a training set of 13107 sinograms and a validation set of 3277 sinograms
    - width: .1 - 200 mm,
    - thickness: .1 - 80 mm,
    - warp: 0 - 4 degrees
  - Models:
    - Principal components analysis (PCA)
    - Auto encoder

Results for Method 2: PCA and auto encoder thickness predictions

- 24 real patients scans were evaluated by the PCA and auto encoder models to predict the thickness recorded in the DICOM header
  - Cranial Caudal (CC) view
  - Taken on General Electric's (GE) SenoClaire Tomosynthesis system
  - DICOM header field (0018, 110A) for body part thickness
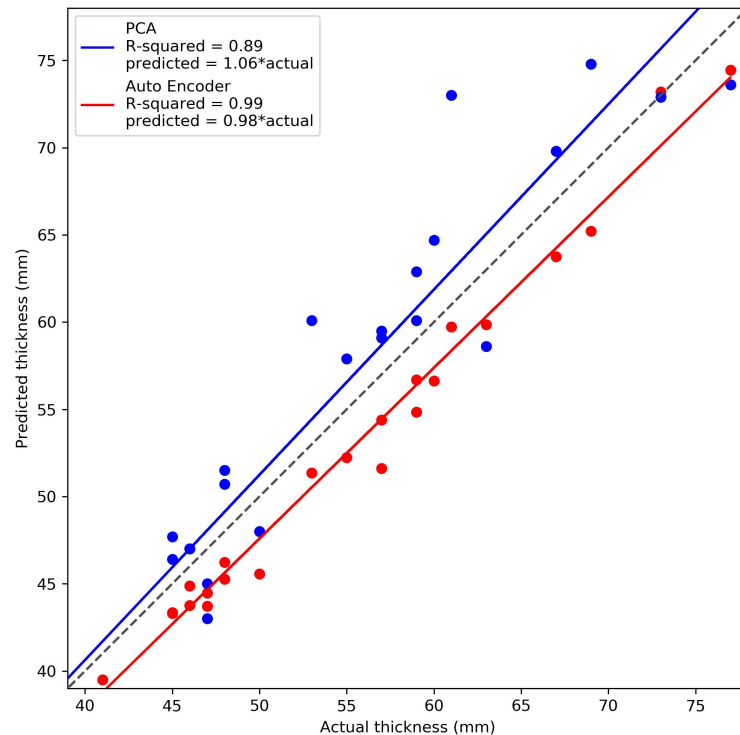
Thickness estimation evaluation

- 24 patient scans were evaluated by both the PCA and auto encoder model
- Predictions were compared to the thickness reported in the DICOM header

|	Mean DICOM Header Thickness (mm)	DICOM header - Predicted Mean (mm)	Standard Deviation (mm)	Minimum Difference (mm)	Maximum Difference (mm)	RMSE (mm)	R^2
PCA Thickness Estimate	53.76	-0.84	3.85	-5.10	5.40	3.86	0.89
Auto Encoder Thickness Estimate	53.76	2.67	0.90	1.12	4.16	2.56	0.99

Full thickness estimates examples

- Final PCA and auto encoder models were used to predict all cross sectional slices from the chest wall to the nipple for a single patient

Green - Thickness recorded in the DICOM header

Orange - Thickness estimated via PCA

Red - Thickness estimated via auto encoder
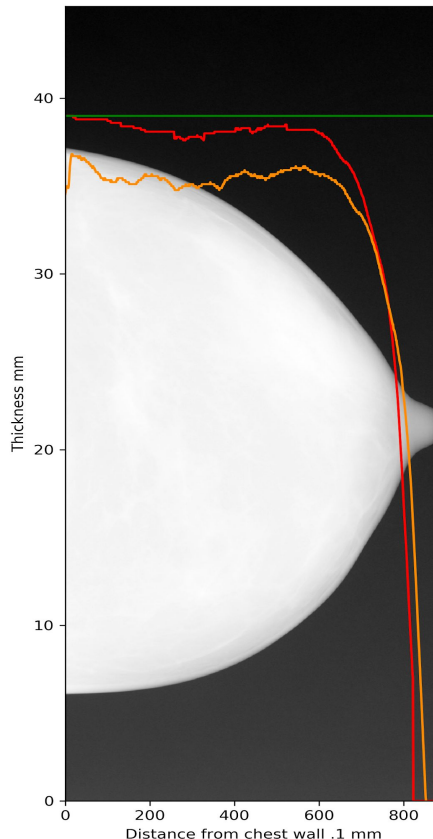
Tilt and warp geometrical predictions

- Calculating tilt:
  - We assume that the breast is in contact with the compression paddle out to ⅔ distance from the chest wall.
  - We exclude 1 cm from the chest wall due to chest wall artifacts such as muscle and skin
  - A slope can be calculated by the change in thickness as we move away from the chest wall

	Units	Mean	Standard Deviation	Minimum	Maximum
Auto Encoder Warp Estimates	**Degrees**	**0.11**	**0.04**	**0.08**	**0.23**
Auto Encoder Tilt Estimates	**Degrees**	**0.06**	**0.61**	**2.7 E-04**	**1.02**

Concluding remarks

- We have demonstrated an ability to derive the geometrical parameters (thickness, width, warp, and tilt) of a compressed breast from its sinograms using an auto encoder
- With an accurate thickness model, we can work towards creating 3D lipid, water, and protein volumes of the breast
- We have shown how simulation and simulated data can be used to build translational models which can benefit from addition of real data downstream.

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