Breast CT (with PET) for Screening, Diagnosis, and Breast Cancer Treatment

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R01
R01
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Breast CT (with PET) for Screening, Diagnosis, and Breast Cancer Treatment

Breast Cancer: 1/8 U.S. Women will be diagnosed
~43,000 deaths per year in U.S.
Second leading cause of cancer death in women
Early detection of breast cancer ➔ better prognosis
Mammography ➔ breast cancer screening
Women age 40 and up
Breast CT (with PET) for Screening, Diagnosis, and Breast Cancer Treatment

Motivation / System Design & Fabrication
Breast CT Imaging
Radiation Dosimetry
Image Quality Evaluation
Breast Image Analyses
Biopsy and Cancer Therapy
Summary
Motivation / System Design & Fabrication

Breast CT Imaging

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Summary
cone beam breast CT system
Varian 4030CB
194 mm pixels
2x2→388 mm
1024 x 768 x 30 FPS

Kollmorgen Motor
- Propulsion
- Bearing
- Angle Encoder

Comet 1 kW Tube
12.5 mA at 80 kVp
Fabrication
~2003
Fabrication
~2007

bodega
calibration, correction, and reconstruction

Geometric Calibration

\[
u_{wr} = y_{obj} \cdot \frac{D + u_{wr} \cdot \sin \phi}{C + x_{obj} \cdot \cos \phi} \\
v_{wr} = z_{obj} \cdot \frac{D + u_{wr} \cdot \sin \phi}{C + x_{obj} \cdot \cos \phi}
\]

Hounsfield Unit Calibration

Flat Field Correction

\[
I_{\text{corr}} = \frac{I_{\text{raw}} - I_{\text{r-offet}}}{I_{\text{g-offet}}}
\]

Image Reconstruction

17°
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Summary
16.6 Second Acquisition Time
500 views (30 FPS)
80 kVp  3-8 mA
(50 – 133 mAs)

pendant geometry breast CT scanner
Breast CT Imaging:

~Same radiation dose as two view mammography

~360 patients imaged on two UC Davis bCT

~60 patients imaged with pre/post iodine contrast

(100 ml visopaque 320 @ 4 4ml/sec, ~100 sec delay)

~7 patients imaged with PET/CT

(5 mCi $^{18}$FDG)

~4 patient hands imaged PET/CT for rheumatoid arthritis

(10 mCi $^{18}$FDG)

*First in human (cone beam bCT) – Nov 22, 2004*
Pre-pectoral Saline Implants

Diagnosis: IDC/ILC

January 2005

Tumor is seen on many images
bCT (no injected contrast)
bCT (with contrast)
Contrasted Enhanced breast CT

pre

post

Malignant

benign
Malignant tumors tend to enhance more than benign lesions.
PET / CT for dedicated breast imaging

ramsey badawi
simon cherry
abhijit chaudhari
spencer bowen
Invasive Mammary Carcinoma

Whole-body PET/CT

Dedicated breast PET/CT

Pt 138
Scanning of the uncompressed breast with dedicated breast PET/CT can accurately show suspected lesions in 3 dimensions. Presented here are the CT, PET, and fused images of a 45-year-old patient who presented with palpable, mammographically and MM-20 mm lesion found at the 3-o clock position. In the fused and PET images, the lesion is shown not to overlap any normal tissue as seen on CT.

See page 1480.
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Summary
Dose is size dependent!

2001 tape measure results (N = 200)

2008 assessment on bCT images (N = 137)

X = 13.4 cm
\[\sigma = 2.0 \text{ cm}\]
Median = 13.6 cm
Mean Glandular Dose in Mammography

two-view mammography dose versus CB thickness

Average of 4 mammo systems
Monte Carlo Assessment of Dose Deposition

breast modeled as cylinder

SIERRA MC code used

monoenergetic functions

X-ray Energy (keV)

uGy per million photons

10 cm dia

18 cm dia

SIC=45 cm FOV=20 cm
50% glandular/50% adipose
Mean Glandular Dose in Breast CT

spectral model*

polyenergetic functions

Dose in breast CT is set to be **EQUAL** to the dose of two-view mammography for that women.
Dose assessment repeated by Karellas and by Glick
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Summary
Spatial Resolution: MTF measurements
MTF: computer simulation

temporal lag of detector

focal spot measurement

scanner motion

measured detector MTF

\[ g(t) = f \cdot A \cdot \left[ a_1 \cdot (1 - \exp(-t/T_1)) + a_2 \cdot (1 - \exp(-t/T_2)) + a_3 \cdot (1 - \exp(-t/T_3)) \right] \]
MTF simulations (worst case at periphery)
Contrast Resolution: NPS measurements

\[ NPS(u,v) = \frac{|F(u,v)|^2}{N_X N_Y} \Delta_X \Delta_Y \]

coronal

sagittal

axial

cone angle
Contrast Resolution: NPS measurements

RECON algorithm

Near-Neigh

Bilinear

Ramp

Shepp-Logan

Slice Thickness

x-ray tube mA
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Summary
Breast Glandular Fraction

Nathan Packard  Clare Huang
Glandular Tissue Segmentation: Glandular Fraction

- Risk assessment & Dosimetry
- Validation of 2D approaches (M. Yaffe)
Glandular Tissue Segmentation: Glandular Fraction
The myth of the 50-50 breast

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A. Al-Mayah and K. Brock
\textit{University Health Network, University of}

\[ N = 138 \]
\[ \mu = 12.3\% \]
\[ \sigma = 8.5\% \]
2.5% loss in breast density every decade
Receiver Operating Characteristic (ROC) Curve Basics

![ROC Curve](image)

- Sensitivity
- $1 - $specificity
Any medical test produces data which can be considered the decision parameter. Both normal and abnormal patients will undergo that test, and the trained physician applies a decision threshold to “call” normals from abnormals.
Sensitivity is the accuracy of diagnosis in all patients who are abnormal.

\[
\text{sensitivity} = \frac{TP}{TP + FN}
\]

- **TP**: True Positive
- **FN**: False Negative
specificity = \frac{TN}{TN + FP}

Specificity is the accuracy of diagnosis in all patients who are normal.
Sliding the decision threshold (t), one trades off sensitivity and specificity.
receiver operating characteristic (ROC) curve

real world

ideal performance

pure guessing

sensitivity

1-specificity
Computer Observer Studies

Nathan Packard

Breast CT data

Synthetic spherical lesions, SKE

Projection Images ~mammography

Projection Images ~mammography
Pre-whitened Matched Filter

$$\text{PWMF} = \text{FT}^{-1} \left\{ \frac{\text{FT}\{S(x,y)\}}{\overline{\text{PS}(x,y)}} \right\}$$
Prewhitened Matched Filter
Thick Slices (Mammo)

Prewhitened Matched Filter
Thin Slices (breast CT)
Pre-whitened matched filter – “ideal observer”
1000 true and 1000 non-lesions per bCT – ~380 bCT data sets
Receiver Operating Characteristic (ROC) Curve

- True Positive Fraction
- False Positive Fraction
- 95% specificity
- sensitivity
Breast CT

Mammo

Sensitivity @ 95% Spec

Simulated Lesion Diameter (mm)
Simulated Lesion Diameter (mm)

Sensitivity @ 95% Specificity

Breast CT

Mammo

30%
Evaluation of Anatomical NPS
\[ N_{PS}(f) = N_{PS_a}(f) + N_{PS_q}(f) \]

\[ N_{PS_a}(f) = \alpha f^{-\beta} \]

Burgess, et al

projection image processing

Hanning filter

2D FFT

$\Sigma/n$

$NPS(f)$

Frequency (cy/mm)

100.00

10.00

1.00

0.10

0.01

0.01

0.10

1.00

10.00

$NPS(f)$

$f = \sqrt{u^2 + v^2}$
breast CT processing

Hanning filter

2D FFT

$\Sigma/n$

$f = \sqrt{u^2 + v^2}$

2D-NPS

NPS(f)

Frequency (cy/mm)

- Logarithmic scale on the y-axis
- Linear scale on the x-axis

Graph showing the relationship between frequency and NPS.
Characterizing anatomical variability in breast CT images

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\[ \beta_{bCT} = \beta_{mammo} - 1 \]

<table>
<thead>
<tr>
<th>Modality</th>
<th>( N )</th>
<th>Average exponent</th>
<th>Standard deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mammograms</td>
<td>213</td>
<td>2.83</td>
<td>0.35</td>
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<tr>
<td>(Burgess et al.)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>bCT Slices</td>
<td>43</td>
<td>1.86</td>
<td>0.38</td>
</tr>
<tr>
<td>Mammograms</td>
<td>6</td>
<td>3.01</td>
<td>0.32</td>
</tr>
<tr>
<td>bCT Slices</td>
<td>6</td>
<td>1.99</td>
<td>0.33</td>
</tr>
</tbody>
</table>
N=17 patients
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breast cancer screening and diagnosis

breast CT platform

breast CT data ($512^3$)