Concepts for High-Resolution Low-Dose CT of the Breast

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Disclosures
- WAK is founder, shareholder and CEO of CT Imaging GmbH, Erlangen, Germany.

Breast CT
- Motivation
- Prior art
- Goals
- Necessary technology
- Expected performance of dedicated high-resolution low-dose breast CT
- Plans for (pre-)clinical evaluation

Performance of mammography in breast cancer screening:
- Sensitivity 62% - 88%
  Source: Carney et al. Annals of Internal Medicine 2003
- Sensitivity 63% - 78%

Projection image vs. CT image (in the same patient)

"Unfortunately, a mammogram, like other radiographs, is a two-dimensional planar image with inherent limitations in identifying three-dimensional lesions, particularly in the relatively homogeneous soft tissues of the breast."
Dedicated Breast CT
Announced and patented by GE as “CT Mammography” (CTM) in the 1970s
Chang et al., Cancer 46, 939-946 (1980)

Scan time: 1 min; Slice thickness: 1 cm; Contrast: 300 ml
Perrone A et al. AJR 2008; 190:1644-1651

"Dynamic MDCT can be used in the evaluation of selected patients with suspected breast tumours."

Dedicated breast CT scanner at UC Davis (since about 2005)
Several research groups active in the USA at present.

Cone-beam CT geometry
Images: Courtesy of John Boone, UC Davis

Results: Overall, CT was equal to mammography for visualization of breast lesions. Breast CT was significantly better than mammography for visualization of masses (p<0.002); mammography outperformed CT for visualization of microcalcifications (p<0.006).

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** Conclusions: Some technical challenges remain, but breast CT is promising and may have potential clinical applications."
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Innovative breast CT must offer
- full 3D imaging capabilities
- high spatial resolution (100 µm or better) for the detection of microcalcifications
- good soft tissue delineation
- dynamic scanning for the differentiation of benign and malignant lesions
- dose levels similar to screening mammography
- integrated biopsy facility
- absence of painful compression
High-resolution CT
Micro-CT scan of surgical specimens

DCIS specimen * embedded in parafin

Micro-CT
40 µm resolution

* Specimen provided by M. Beckmann, Erlangen

Contrasts in breast tissue

<table>
<thead>
<tr>
<th>KV</th>
<th>Adipose (mean)</th>
<th>Tumor (mean)</th>
<th>Calcification (e.g.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>40</td>
<td>-440</td>
<td>-180</td>
<td>8200</td>
</tr>
<tr>
<td>60</td>
<td>-400</td>
<td>-160</td>
<td>6000</td>
</tr>
<tr>
<td>80</td>
<td>-350</td>
<td>-100</td>
<td>5000</td>
</tr>
</tbody>
</table>

gland - fat ~ 200 HU
gland – calcification > 5000 HU
@ 40 µm resolution

Dose assessment by Monte Carlo methods

CT
120 kV
Breast CT
60 kV
Mammography
30 kV

14 cm diameter
4.5 cm thickness

Determination of 3D dose distributions by simulations is established and confirmed by measurement. They apply to breast CT, mammography and tomosynthesis in equal manner.

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Breast CT scanner concept

Transition from
single-circle flat detector to spiral CT detector

Photon counting CdTe detector

• Curved detector built up scalable of discrete CdTe tiles with 100 µm pixel size
• Count rate: $10^6$ ph./mm²/s
• Frame rate: 1000 proj./s
• Two thresholds for energy discrimination
• Detection efficiency and geometric efficiency close to 100% (exceeding the performance of today's CT detectors)

Project consortium:
CT Imaging GmbH, Erlangen / D
IMP U of Erlangen, Erlangen / D
XCounter AB, Danderyd / S

Novak T, Schilling H, Kalender WA. Patent application 2009

Detection principles

- Scintillator
- Scintillator (structured)
- Direct converter

Point Spread Functions (PSF)

Spatial resolution

Simulations

Measurements


Simulation results for breast CT

Phantom
14 cm diameter
16 cm length

Scan parameters
2 s / 2000 proj. / 360°
100 µm FS /
Dose: 3 mGy AGD

Modelling
Reconstruction


Dedicated CT of the breast


Patient- and biopsy-friendly gantry

Demands
- Comfortable patient positioning with coverage of the full breast and the axilla
- Variable table height (ca. 70 - 170 cm)
- Sequential and spiral scanning (25 cm in 12 s)
- Easy access to the patient for biopsy and therapy

Kalender WA, Althoff F. Patent application 2010

Measurements with the prototype system

Modulation transfer function

Wire phantom
(10 cm diameter)

MTF plot
(30 µm Ni74/Cr20 wires)


MTF_{90%} : 5.6 lp/mm
Measurements with the prototype system
ACR phantom

Fibers (nylon fiber)
1. 1.56 mm
2. 1.12 mm
3. 0.89 mm
4. 0.75 mm
5. 0.54 mm
6. 0.40 mm

Specks (Al₂O₃ speck)
7. 0.54 mm
8. 0.40 mm
9. 0.32 mm
10. 0.24 mm
11. 0.16 mm

Masses (thickness)
12. 2.00 mm
13. 1.00 mm
14. 0.75 mm
15. 0.50 mm
16. 0.25 mm

Mammography

Measurements with the prototype system
ACR phantom: fibers & masses

Fibers
Mammography
Breast CT

Masses

Even for the ideal ACR phantom situation with no structures superimposed mammography misses small structures shown by breast CT!

Measurements with the prototype system
ACR phantom: microcalcifications

Even for the ideal ACR phantom situation with no structures superimposed mammography misses small structures shown by breast CT!

Expectations for high-res. breast CT

- Good detectability of
  - microcalcifications of 100-150 µm diameter,
  - soft tissue lesions of 2 mm diameter,
  - at an AGD of 2 to 4 mGy!
- Dynamic contrast-enhanced scanning for improved analysis of differential uptake.
- A “one-stop shopping” modality for complete diagnostic workup on one device.
- First system tests before end of 2012, clinical tests starting in mid 2013.

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Thank you for your attention!