Ultrasound Tomography: A Breast Imaging Modality Whose Time Has Come

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History of Medical Ultrasound Tomography

- 1950's – Pulse-echo technique (Wild and Reid)
- 1950's – Mechanical rotation in a water bath
- 1978 – First cross-sectional transmission images of the breast (Howry et al)
- Use of sound speed and attenuation to characterize tissue (Glover et al, Greenleaf and Johnson)
- 1981 – First cross-sectional images that combine reflection and transmission imaging (Carson et al)
- 1997 – First clinical use of diffraction tomography (Andre et al)
- 2007 – Full wave-based reconstructions of sound speed and attenuation for whole breast (Johnson et al; Techniscan Medical)
- 2007 – Simultaneous reflection and transmission imaging of the whole breast (Duric et al)
- 2008 – Attenuation based tomography (Marmarelis et al)
- 2010 – True 3-D reflection tomography (Ruiter et al)
- 2013/2014 – FDA clearances for the SoftVue system (Delphinus Medical)

Screening Dense Breasts

- X-ray mammography detects ~ 5 cancers per 1000 screens
  - Low sensitivity in women with dense breast tissue
  - Tomosynthesis may help
    - unlikely to create a paradigm shift in performance
    - generates even higher levels of ionizing radiation
  - MRI can address these limitations, but
    - long exam times and the use of contrast agents.
    - expensive for routine use although “fast MRI” holds promise
    - PEM and MBI limited by cost and radiation concerns.
  - Other modalities such as OCT and PAT are still in early development
  - Studies show effectiveness of HHUS and ABUS for women with dense breasts.
    - Up to 4.5 extra cancers detected per 1000 screens.
    - Predominantly node-negative invasive cancers

Screening Ultrasound (US) Studies

<table>
<thead>
<tr>
<th>Study Authors</th>
<th>Year</th>
<th>Type</th>
<th>Exams</th>
<th>US Only</th>
<th>Cancers Yield per 1000 S Irene</th>
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</thead>
<tbody>
<tr>
<td>Brem, et al.</td>
<td>2014</td>
<td>Multi</td>
<td>ABUS</td>
<td>15,318</td>
<td>30.96</td>
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<tr>
<td>Berg, et al.</td>
<td>2012</td>
<td>Multi</td>
<td>HHUS</td>
<td>7,473</td>
<td>4.28</td>
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<tr>
<td>Hooley, et al.</td>
<td>2012</td>
<td>Single</td>
<td>HHUS</td>
<td>935</td>
<td>3.21</td>
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<tr>
<td>Kelly, et al.</td>
<td>2010</td>
<td>Multi</td>
<td>AWBU</td>
<td>6,425</td>
<td>3.58</td>
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<tr>
<td>Corsetti, et al.</td>
<td>2008</td>
<td>Multi</td>
<td>HHUS</td>
<td>9,157</td>
<td>4.08</td>
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<tr>
<td>Crystal, et al.</td>
<td>2003</td>
<td>Single</td>
<td>HHUS</td>
<td>1,517</td>
<td>3.41</td>
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<tr>
<td>Kolb, et al.</td>
<td>2002</td>
<td>Single</td>
<td>HHUS</td>
<td>13,547</td>
<td>2.76</td>
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<tr>
<td>Kaplan</td>
<td>2001</td>
<td>Single</td>
<td>HHUS</td>
<td>1,862</td>
<td>3.22</td>
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<tr>
<td>Buchberger, et al.</td>
<td>2000</td>
<td>Single</td>
<td>HHUS</td>
<td>8,103</td>
<td>3.95</td>
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<tr>
<td>Gordon, et al.</td>
<td>1995</td>
<td>Single</td>
<td>HHUS</td>
<td>12,703</td>
<td>3.80</td>
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Study Averages

<table>
<thead>
<tr>
<th>Type</th>
<th>Average</th>
<th>NINV</th>
<th>DCIS</th>
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</thead>
<tbody>
<tr>
<td>Mammography</td>
<td>NINV=3.3/1000</td>
<td>NDCIS=0.7/1000</td>
<td></td>
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<tr>
<td>Ultrasound</td>
<td>NINV=3.1/1000</td>
<td>NDCIS=0.2/1000</td>
<td></td>
</tr>
</tbody>
</table>

The Dense Breast Screening Challenge

- US almost doubles invasive cancer detection
- Recall rates also doubled
- Cost benefit trade-off uncertain

Sprague SB, et al Ann Intern Med. 2015 Feb 3;162

Results from UST Scanner at KCI
Tissue specific imaging

UST Imaging Modes

Reflection (B Mode) Imaging

Sound Speed

Attenuation

Stiffness

Quantitative Measurements
ACKNOWLEDGMENTS: This research was supported by the NIH through grant number R44CA165320-01A.

Future of UST

High image quality relies on:
- Dense sampling of the scattered field
- Uniform and strong illumination of the object.
- Physics-based reconstruction algorithms
- Solution requires large amounts of data to satisfy the sampling constraint and advanced computing power to enable physics based modeling for generating the output image.

Image reconstruction techniques:
- Beamforming or SAT techniques for reflection imaging
- Straight ray tomography (backprojection) for transmission imaging
- Curved ray tomography
- Waveform tomography

Moore’s Law

Computational complexity

The Economist (Oct, 2011)
Conclusions

- Adjunctive screening with US increases sensitivity in dense breasts
  - Almost doubles invasive cancer detection
  - Increases call back rates

- UST may lower barriers to adoption for screening
  - UST’s tissue specific imaging may help reduce call back rates
  - Diagnostic studies suggest AUC improvement
  - UST will rapidly improve with time by riding Moore’s Law

PMA trial for supplemental screening planned