Real-time electromagnetically navigated breast cancer surgery

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Breast conserving surgery

- Breast cancer kills more women than any other cancer
- Detected at earlier stage due to screening programs
- Early stage breast cancer is treated by breast conserving surgery (aka) *lumpectomy*
Image-guided wire localization

- Localization needle and wire are placed in the tumor under X-ray or ultrasound.
- But tumor margins are not directly marked by the needle, and it is invisible during surgery.
Problem: positive margins

• Tumor at excision borders
• Additional surgery
  – delays adjuvant treatments
  – causes further trauma
  – increases cost
• Positive margins are reported in 15% - 47% of cases after wire-localization guidance
• Repeat surgery is no longer conserving, 1/3 of those is full mastectomy
EM-tracked tissue locking needle

Method derived from “Wire-Guide” & “EM beacon”
Resulting navigation system

Note: In the actual experiments the phantom was opaque; here we use transparent phantom to show the simulated lesion inside.
Phantom experiment

Screenshot of SlicerIGT interface with registered tumor model

Example of EM navigated model resection showing clear margins on all sides of implanted tumor
Phantom experiment results

- N = 42 synthetic tumors resected by 8 surgical trainees and 2 staff breast surgeons
  - 21 using control method (wire-localization)
  - 21 using EM-navigation
- Positive margin rate
  - Control 42.9% (9 of 21)
  - EM 19.0% (4 of 21)
  - p = 0.18
- Average amount of tissue resected (“cosmesis”)
  - Control 36.3 g (SD =14.5 g)
  - EM 37.7g (SD =9.8 g)
Human cadaver – workflow refinement
Feasibility in the operating room
Infection control

- Designed tracker attachments that are usable through plastic bags
- CAD files available at www.plustoolkit.org
User interactions

• Touchscreen tablet on the operating table, in a sterile bag (X-ray cassette bag)
• Screen sharing and user interaction forwarding (TightVNC)
Workflow driven interface

• Workflow implemented as a slicelet - custom GUI for the 3D Slicer application
• Calibration and real-time visualization uses SlicerIGT - www.slicerigt.org
Dynamic tumor contouring

- Tumor model interactively edited by surgeon. Tapping on the ultrasound images (sterile tablet) extends the existing 3D contour.
Finally: clinical trial
## Trial 1: Palpable tumors

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<th>Patient Number</th>
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<th>3</th>
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<td>Invasive ductal carcinoma</td>
<td>In situ and invasive ductal carcinoma</td>
<td>Benign phyllodes tumor with florid ductal hyperplasia</td>
<td>Benign fibroepithelial lesion</td>
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*Gauvin et al. The Breast Surgery Journal (in review)*
Non-palpable tumors

<table>
<thead>
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<th>Non-palpable tumor trial</th>
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<tbody>
<tr>
<td>Number of cases</td>
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<td>Positive margin for invasive cancer</td>
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<td>Excised tissue volume</td>
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</table>

Problematic aspects:
- 65 user interactions per case
- Technician in the OR

Ungi et al. CARS/ISCAS, 2017
Real-time spatial mapping of electromagnetic tracking error

Youtube Video: https://www.youtube.com/watch?v=R78Dxi5exO4
Google Glass display
Sonic Constraints

Youtube Video: https://www.youtube.com/watch?v=gSz8IHmogMo
Virtual constraints
Navigated margin probe

Youtube Video: https://www.youtube.com/watch?v=ag7fWY27lus
X-ray mammography

- x-ray machine
- compression plates
- breast

Fatty

Scattered Fibroglandular

Heterogeneously Dense

Extremely Dense
Breast Tomosynthesis

Youtube Video: https://www.youtube.com/watch?v=VhvSYl_ZMEs&feature=youtu.be
X-ray breast biopsy
Marking the breast biopsy site

Mammogram following the biopsy with injectable hydrogel markers placed to mark the biopsy site.

Mammogram following the biopsy shows the clips (arrows) placed to mark the biopsy site.
iKnife

- Rapid Evaporative Ionization Mass Spectrometry (REIMS)
- Joule heat ionizes the analytes
- Primarily, lipid components of tissues provide the information
- Other metabolite molecules and certain proteins as well
- Vacuum-driven into mass spectrometry analysis device
- From $<1 \text{ mm}^3$ material, reading takes $<2\text{sec}$

Youtube Video: [https://www.youtube.com/watch?v=pHv4P-TjIHs](https://www.youtube.com/watch?v=pHv4P-TjIHs)
Navigated iKnife in Perk Lab

- Only 1 unit exists outside the inventor’s lab
- Funding for 3 units (for lab, 1 clinical) at $2.5M
- 2 delivered, 1 still to come
- 2 labs at KGH, 1 operating room
- Medtronic Stealth Station ($300,000)
Desorption electrospray ionization (DESI)

- Ambient ionization coupled to mass spectrometry
- Fast-moving charged solvent stream, at an angle wrt sample surface
- Extracts ionized analytes from surface
- Propels these secondary ions to mass spec

- High resolution 0.01mm
- Works on fresh and fixed tissue
“Molecular navigation” challenge

DESI

iKnife / REIMS

Genetic info

US / X-ray / MRI

Optical spectr.

AI / ML

Pathology proven condition
• Cancer
• Normal
• Atypical
• etc,...

Spatio / temporal registration