Tumor bed inspection… and other technologies for positive margin prevention in breast conserving surgery

Guest Lecture, Computer Integrated Surgery

October 9th, 2025

Presented by: Laura Connolly, PhD
Malone Postdoctoral Fellow, JHU

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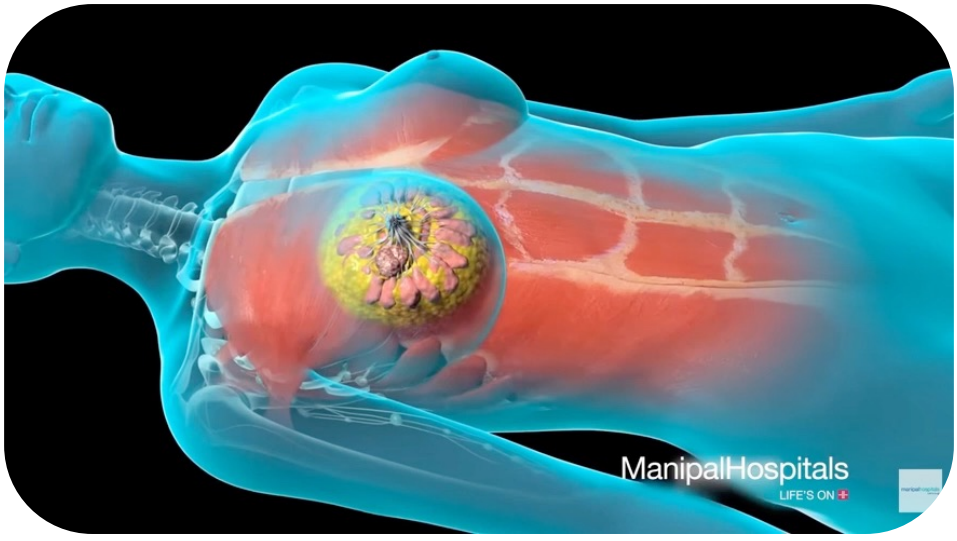
Clinical Motivation

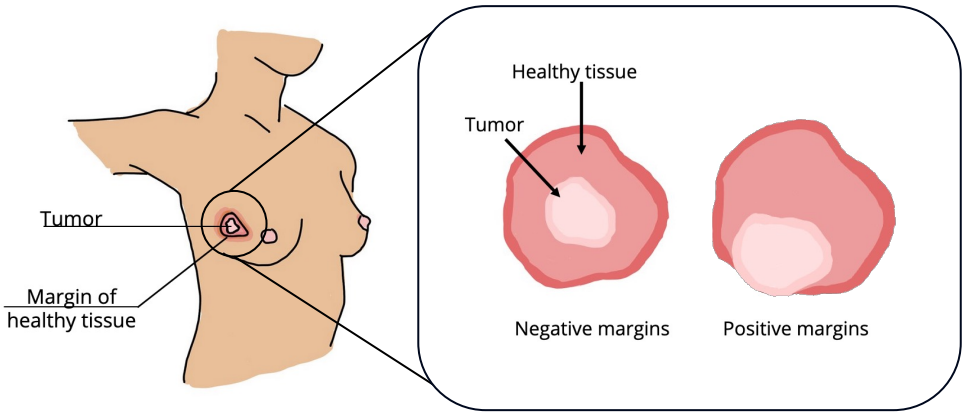


Video credit: Manipal Hospitals. Accessed at: https://www.youtube.com/watch?v=wH-1b3LR8XY

2

Clinical Motivation

Breast-conserving surgery is a common treatment option for early stage breast cancer patients where the tumor is removed and healthy tissue is preserved



3

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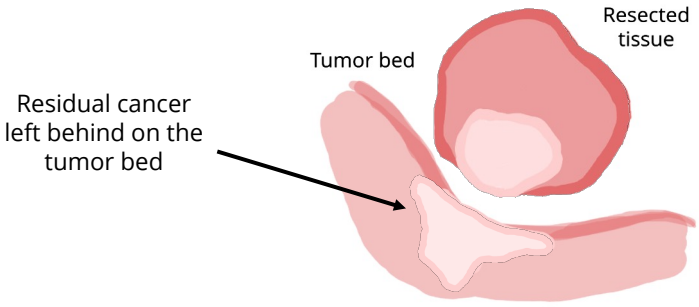

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Breast-conserving surgery is a common treatment option for early stage breast cancer patients where the tumor is removed and healthy tissue is preserved

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Clinical Motivation

Breast-conserving surgery is a common treatment option for early stage breast cancer patients where the tumor is removed and healthy tissue is preserved

Up to 40% of BCS patients experience positive margins[1,2]

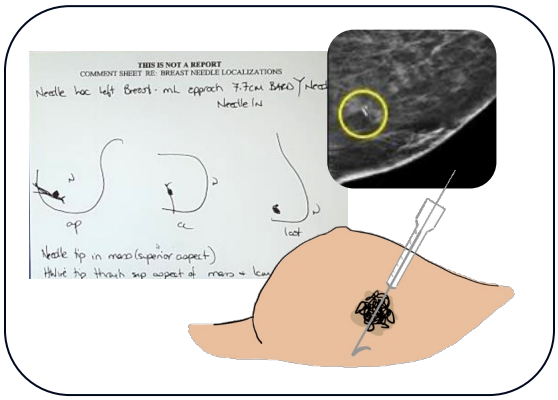
[1]Koning S, Peeters M, et. al *Tumor resection margin definitions in breast-conserving surgery: systematic review and meta-analysis of the current literature*. Clin Breast Cancer, 2018.
[2]Racz JM et. Al. *Intraoperative pathologic margin analysis and re-excision to minimize reoperation for patients undergoing breast-conserving surgery*. Ann Surg Oncol, 2020

6

Why is there such a high failure rate?

Preoperative / intraoperative standard of care

Wire localization or radioactive seed



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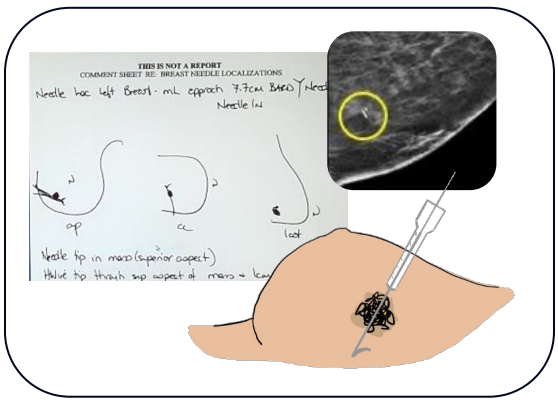

Surgical navigation

8

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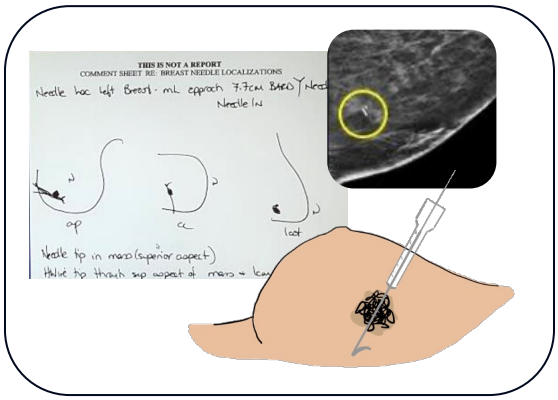
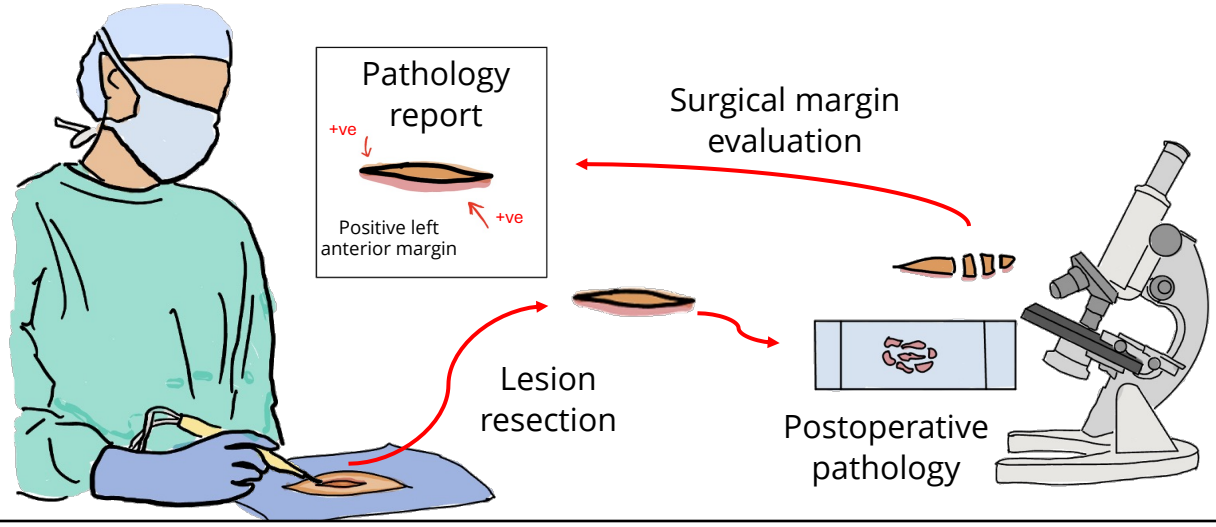


Surgical navigation

9

Why is there such a high failure rate?

Postoperative margin evaluation



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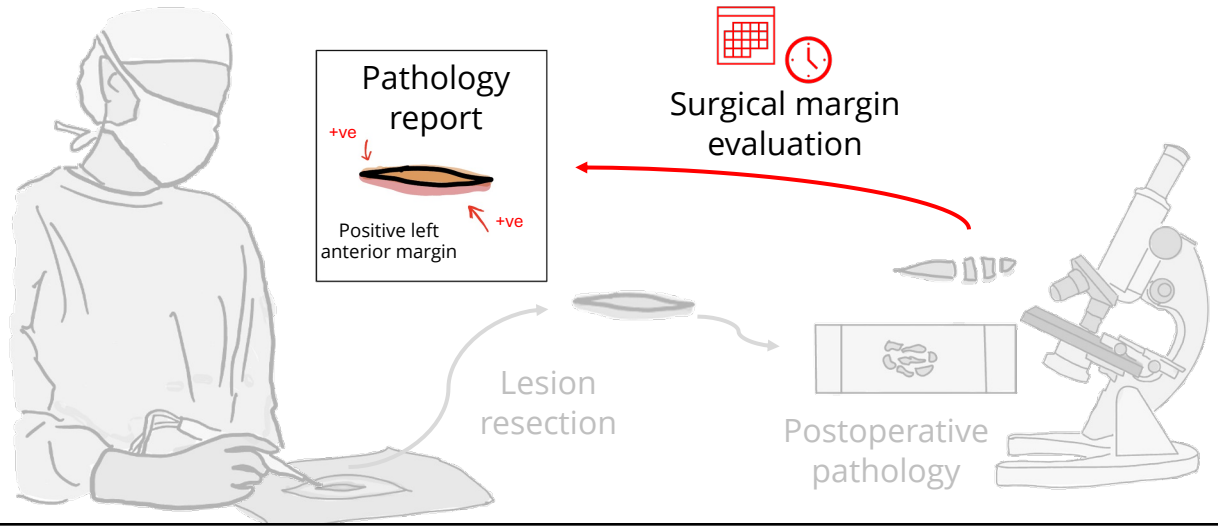
Why is there such a high failure rate?

Postoperative margin evaluation



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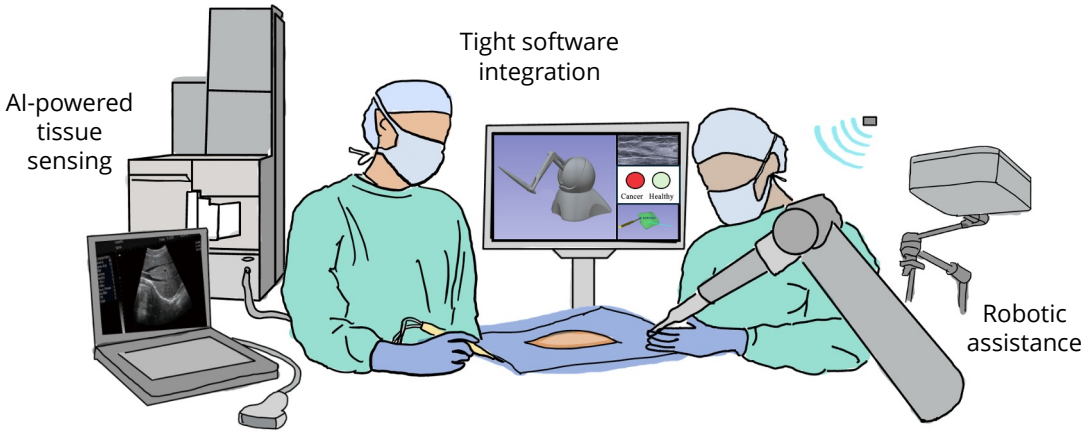
Objectives

Investigate how robotics, tissue sensing, and AI can be used to <u>prevent positive margins</u> in BCS



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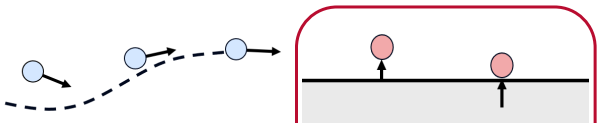
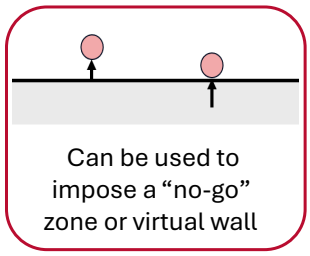
Cooperative robotics

The surgeon and the robot co-manipulate a surgical instrument

Often used for haptic interfaces such as virtual fixtures*



Pull a surgeon along a desired path



Can be used to impose a "no-go" zone or virtual wall

Photo credit: https://www.docmartinortho.vegas/mako-smartrobotics/

*Abbott, Jake J., et al. "Haptic virtual fixtures for robot-assisted manipulation."

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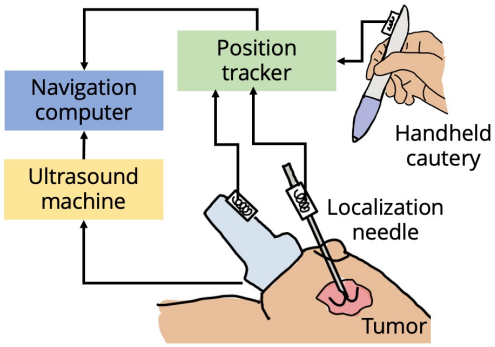
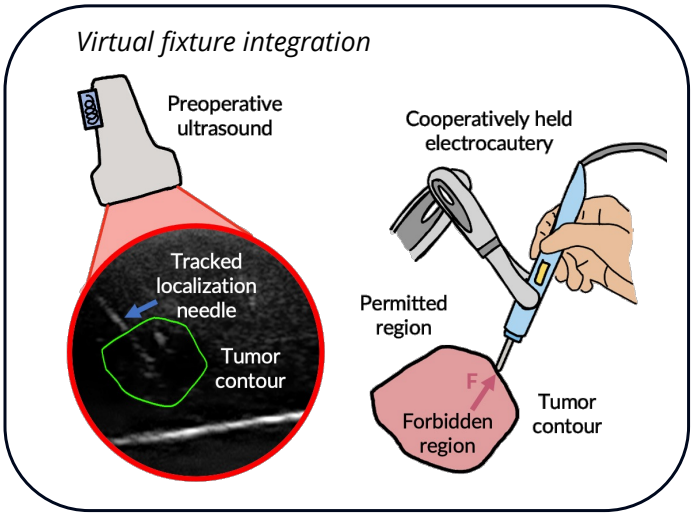
Methodology

LumpNav system



Virtual fixture integration



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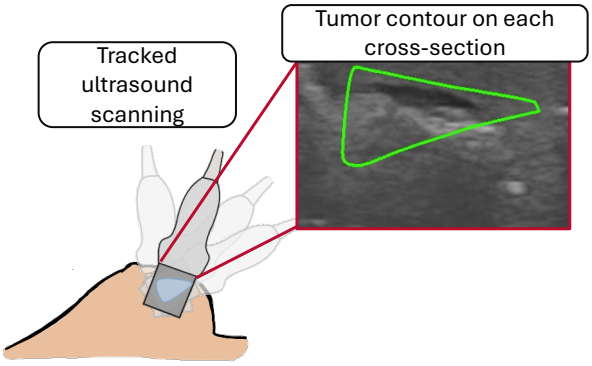
Forbidden region definition

Scan for paper

Method 1: Hand-drawn boundaries



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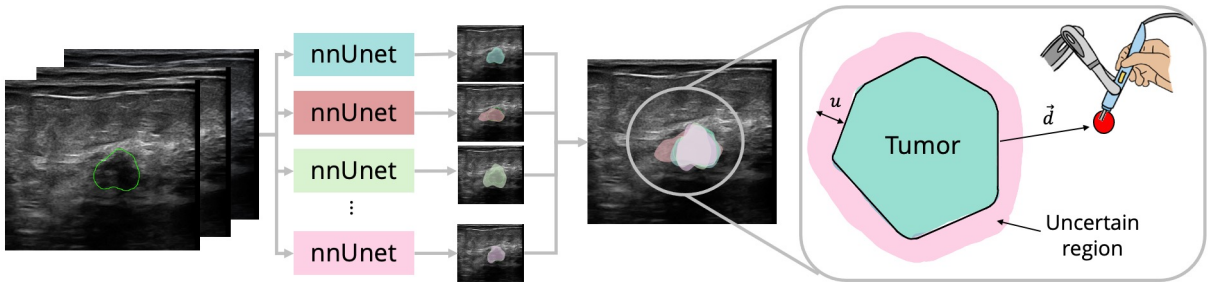
Forbidden region definition

Paper in review

Method 2: AI-augmented boundaries



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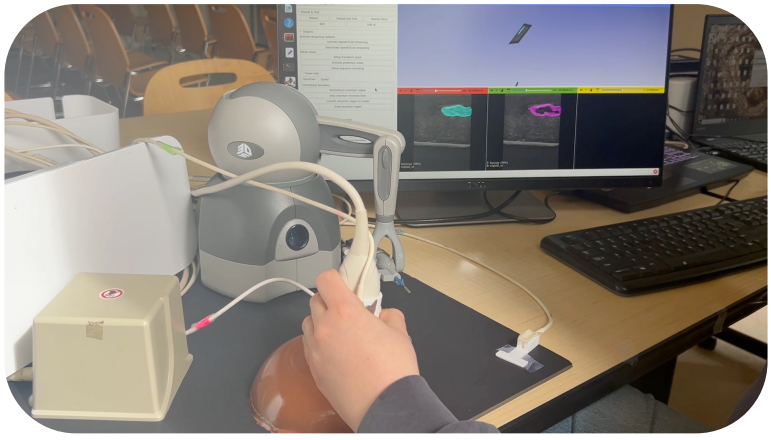

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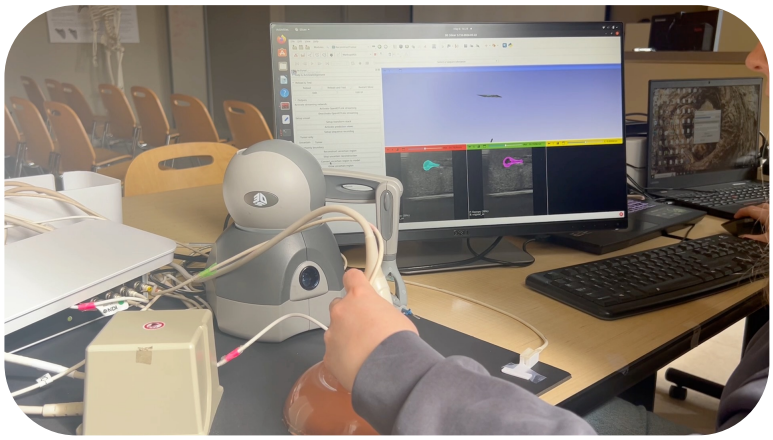

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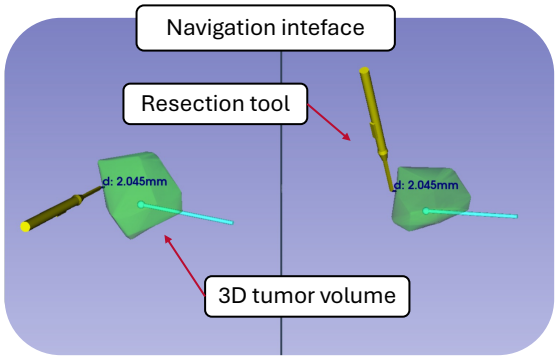

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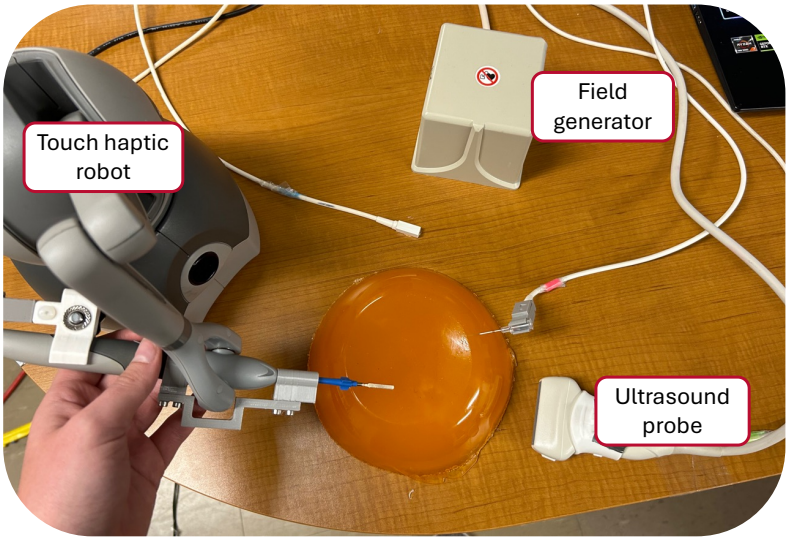
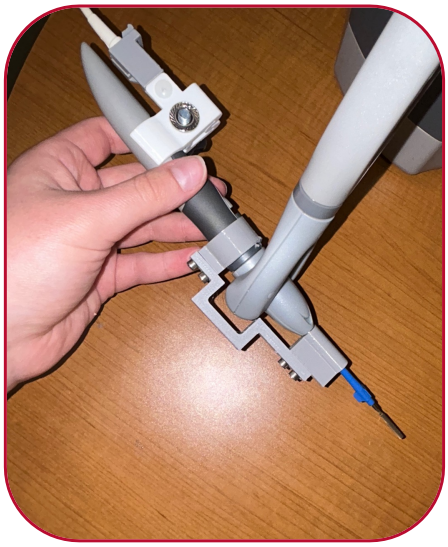
Benchtop testing system





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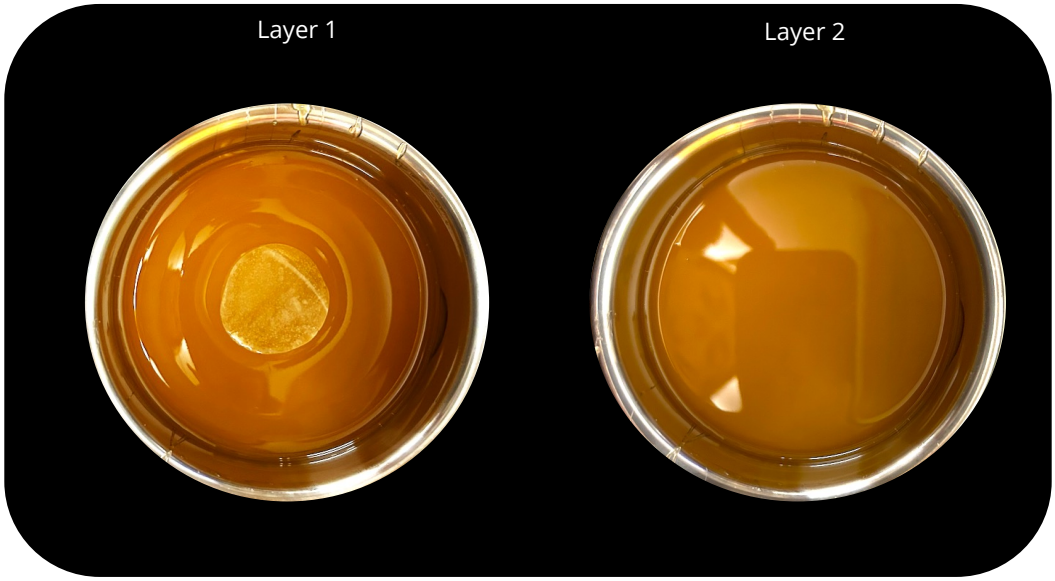
Breast cancer simulants



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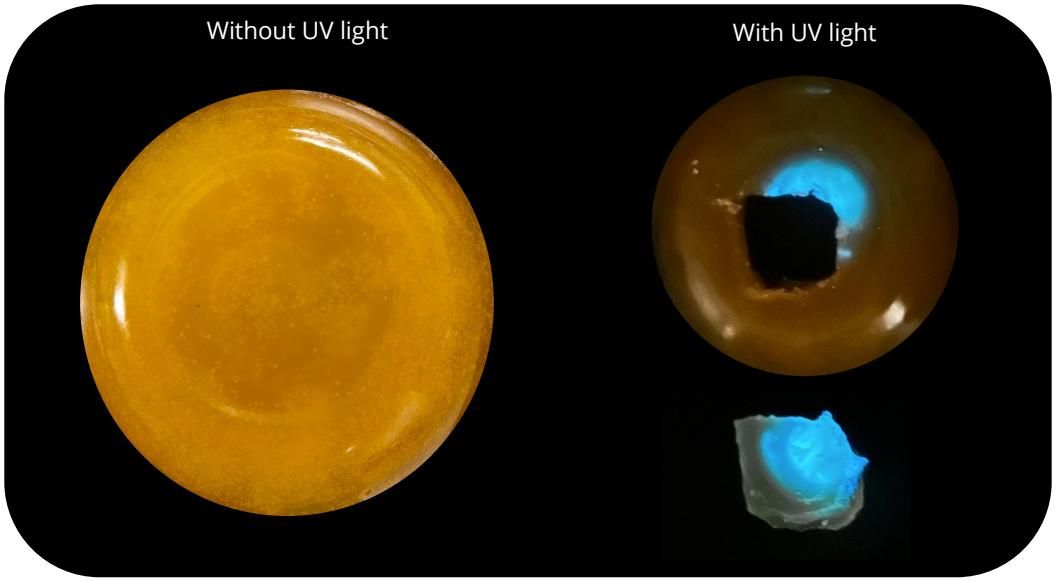

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Pilot study

Scan for paper

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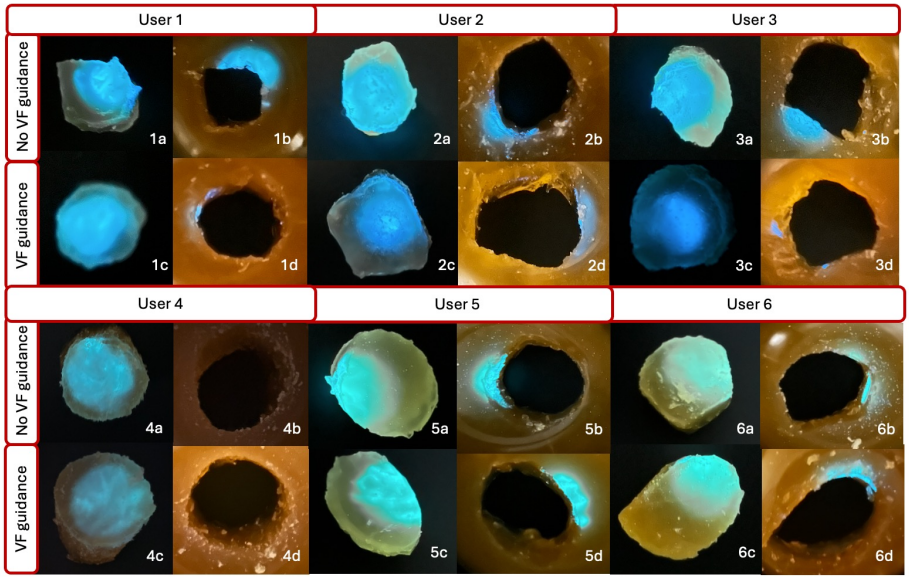
Results

Scan for paper

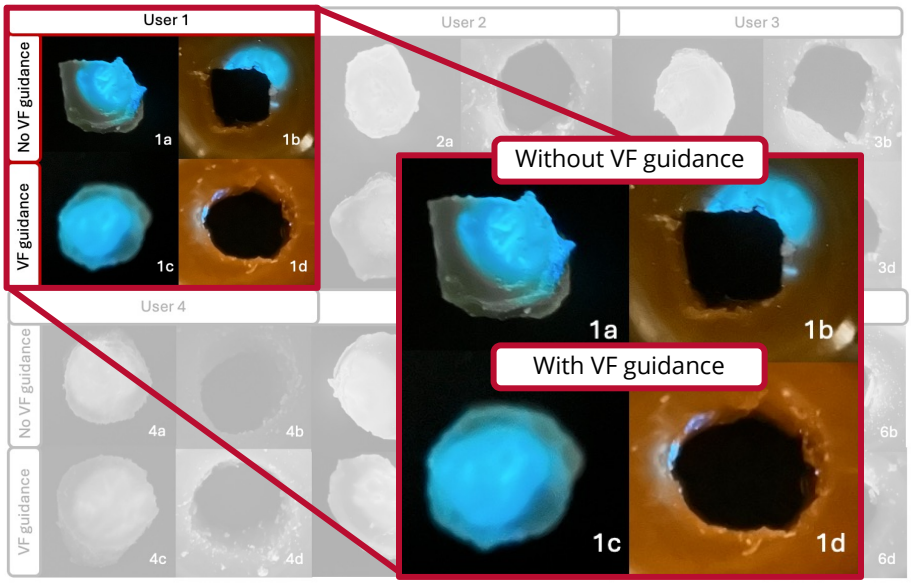


**Note: The color of the residual tumor has no significance

26

Results

Scan for paper



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27

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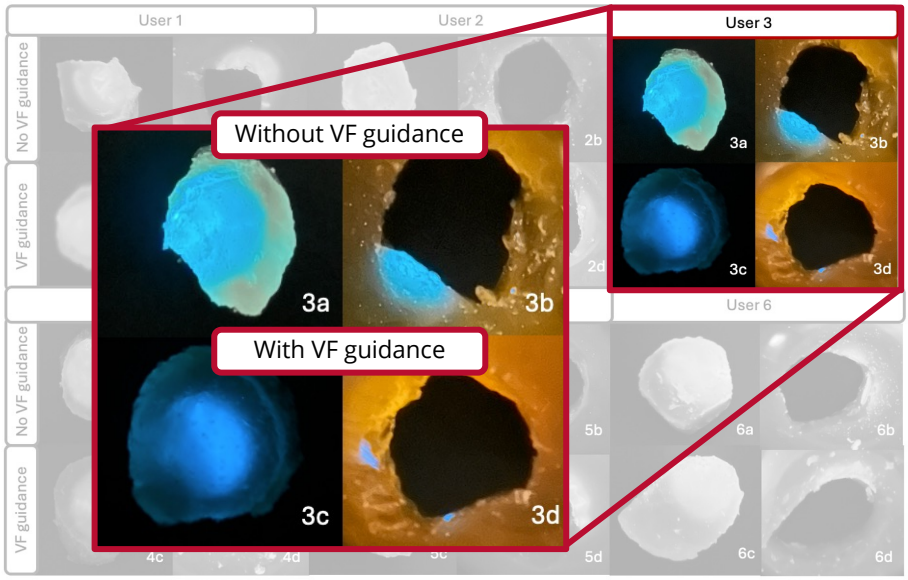

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Results

Paper in review

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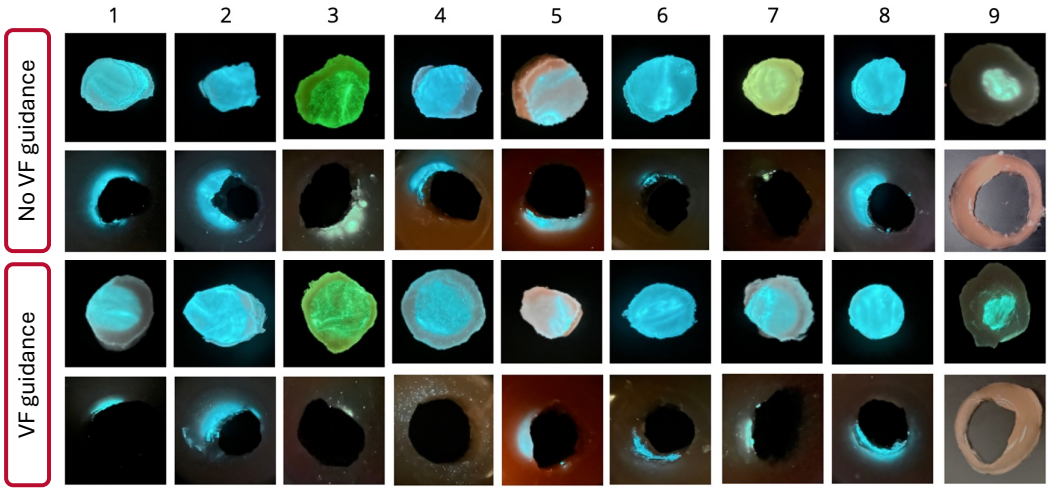

29

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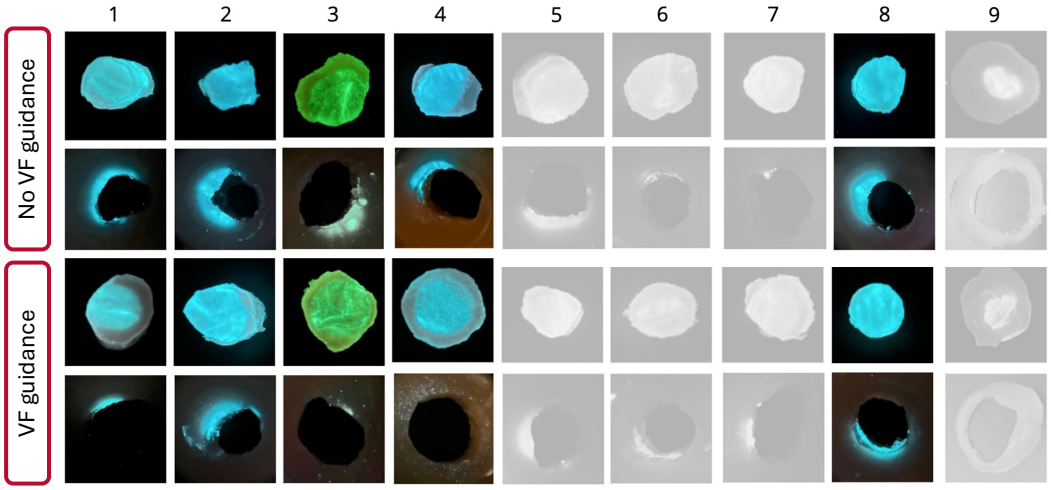

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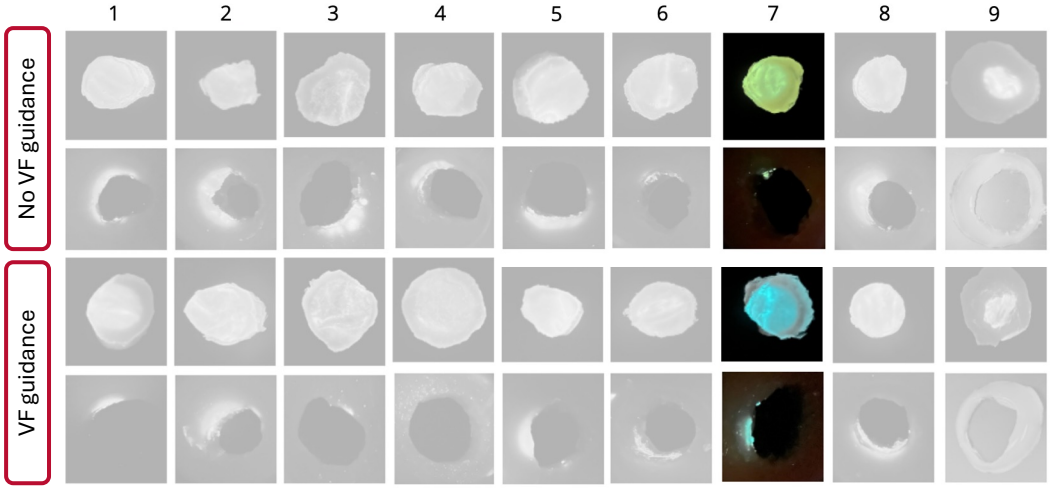

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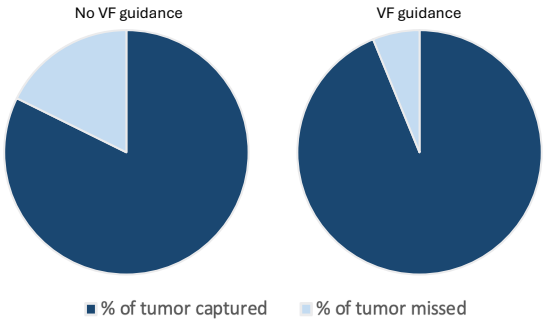

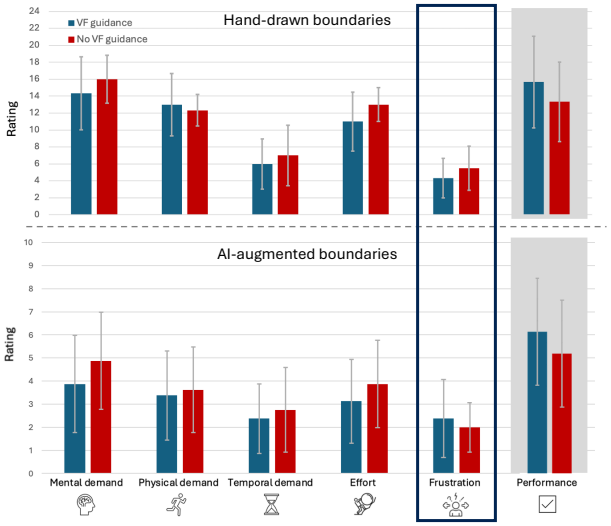

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Limitations and ongoing work

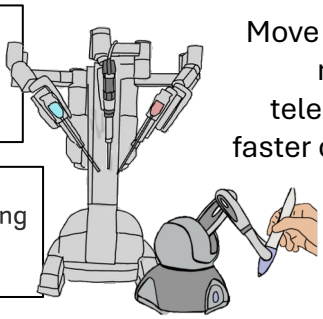
Article | Open access | Published: 02 January 2025

Use of the Da Vinci SP surgical system in robot-assisted nipple-sparing mastectomy: a single-center, retrospective study

ABSTRACT · Volume 10, Supplement 4, 104709 | May 2025 | Open Access

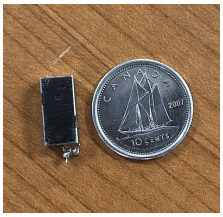
155P Initial experience of robot-assisted breast conserving surgery: A multicenter study

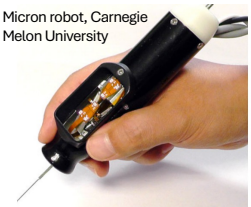
H.J. Choi [1] · S.H. Paek [2] · H.S. Park [3] · J.M. Ryu [4]



Move from cooperative robotics to a telemanipulator for faster clinical translation

Move to a vibrotacticle on-board motor – simpler clinical integration!





Feasibility study in review at SPIE Medical Imaging 2026

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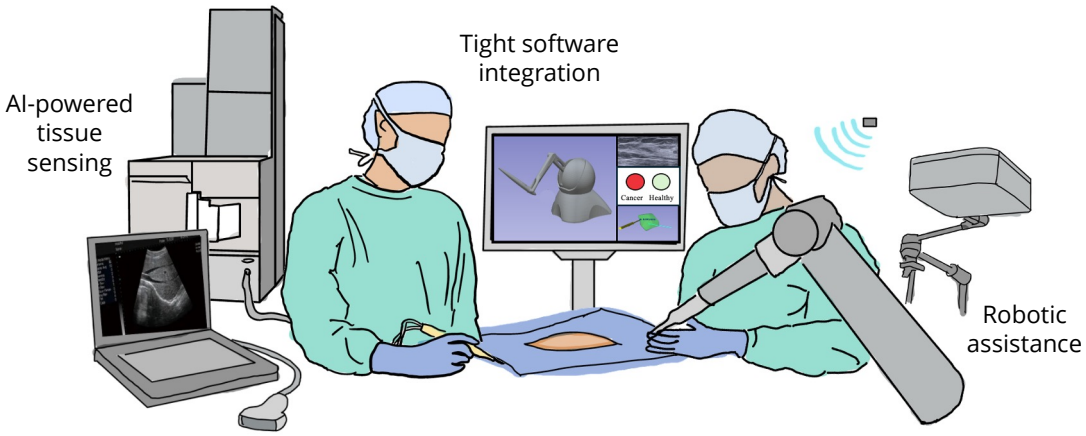

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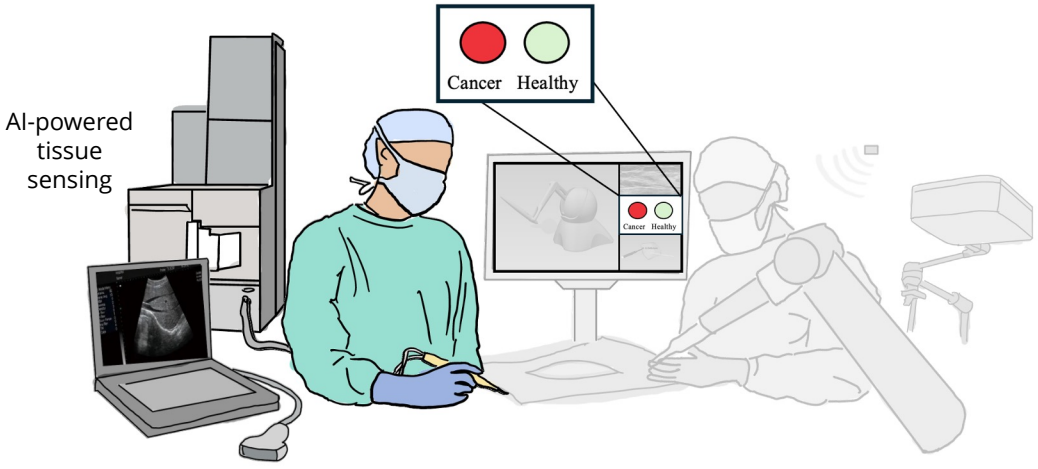

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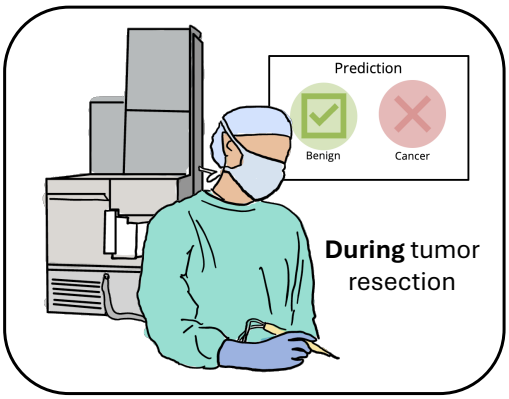

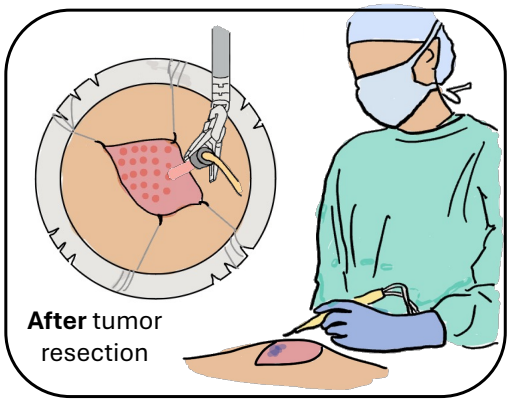

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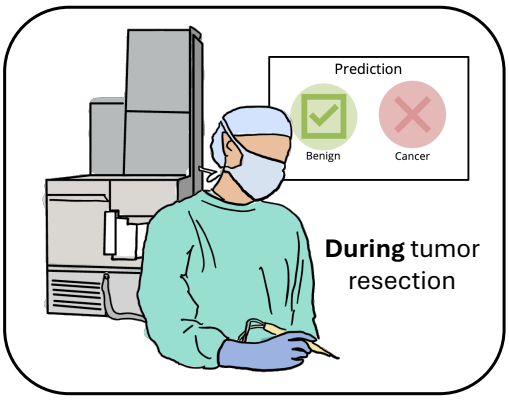

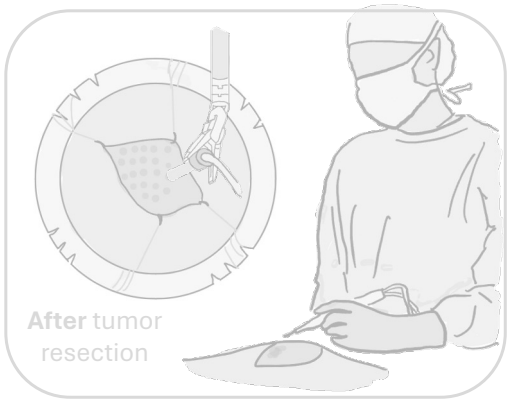

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Mass spectrometry imaging

Intraoperative margin evaluation with mass spectrometry imaging

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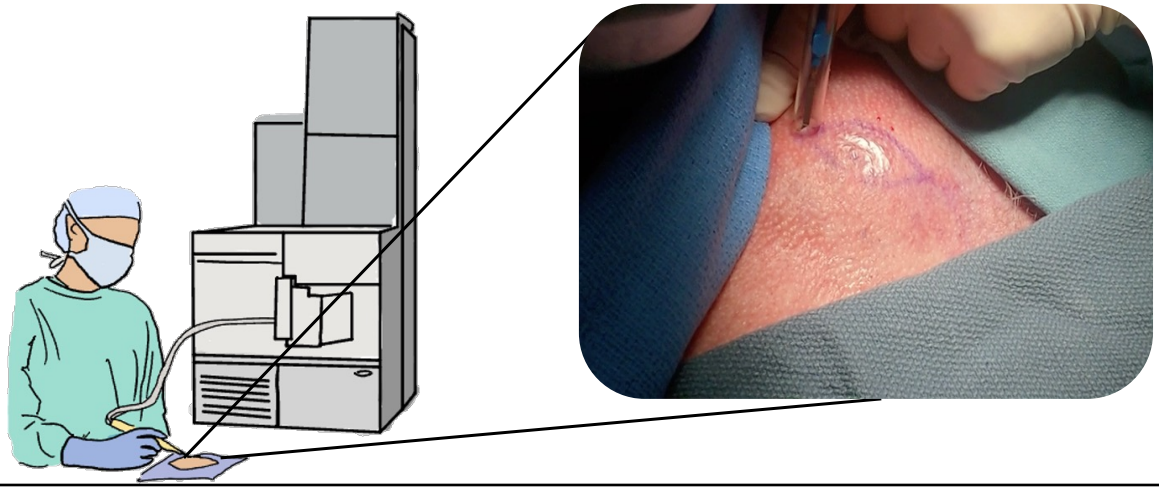
Mass spectrometry imaging

Intraoperative margin evaluation with mass spectrometry imaging



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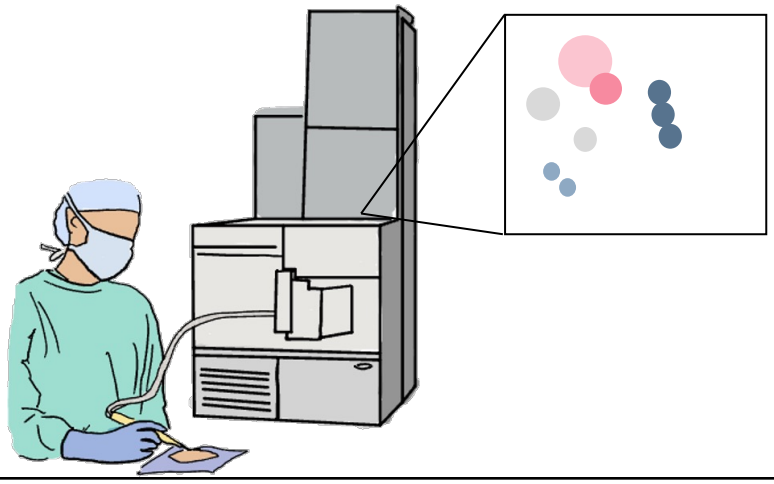

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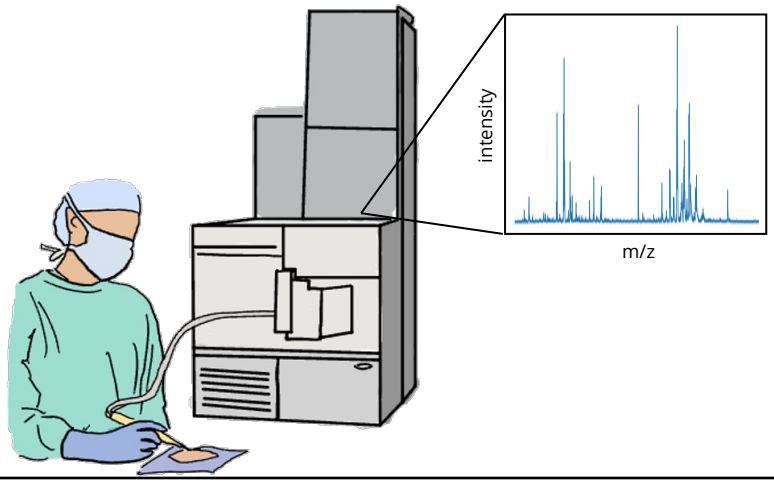

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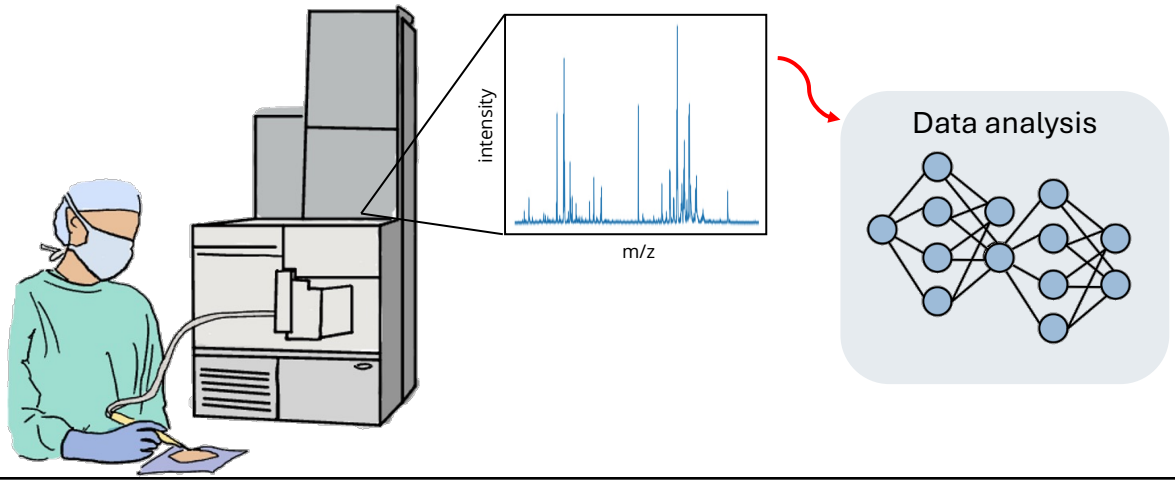
Mass spectrometry imaging

Intraoperative margin evaluation with mass spectrometry imaging



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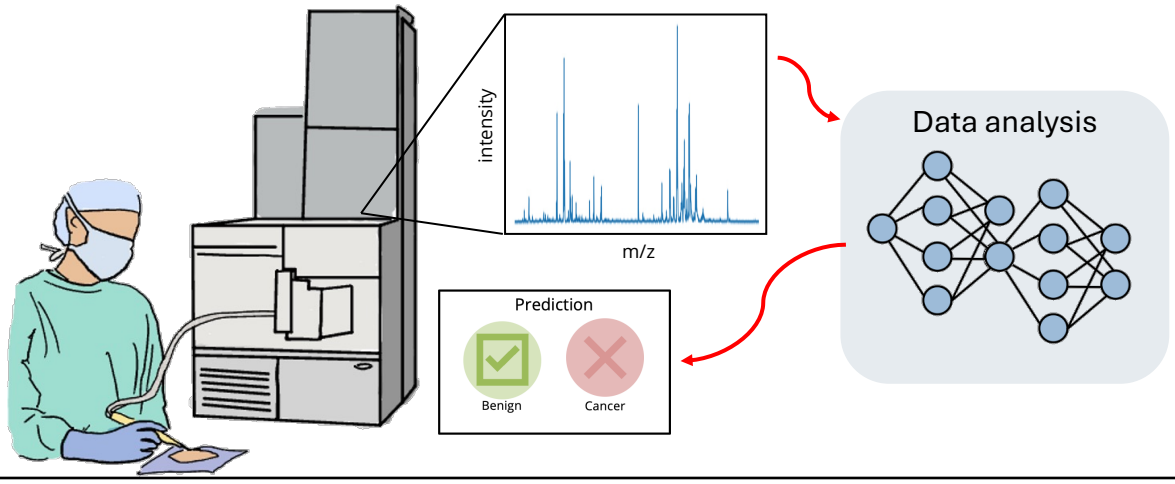
Mass spectrometry imaging

Intraoperative margin evaluation with mass spectrometry imaging



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Mass spectrometry imaging

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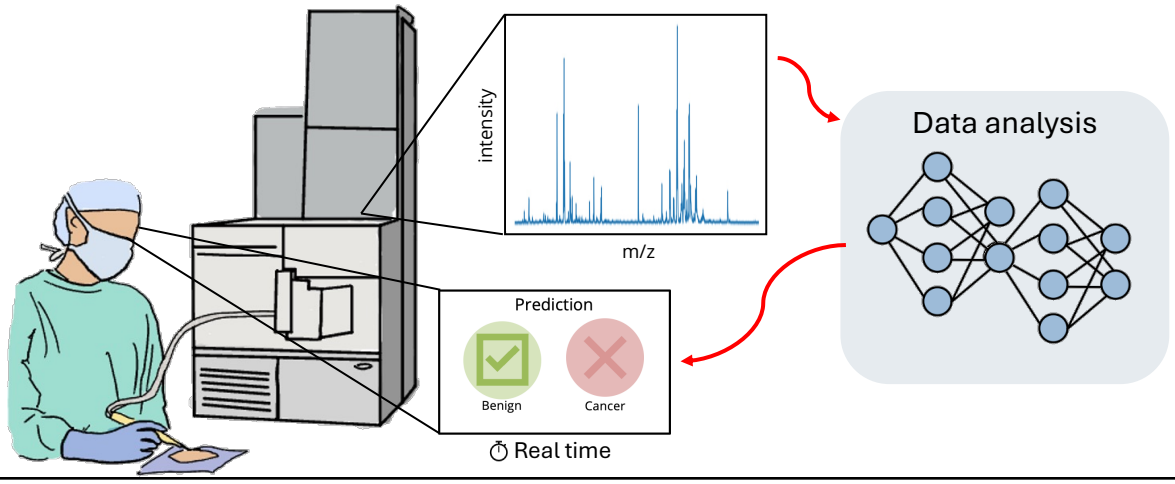

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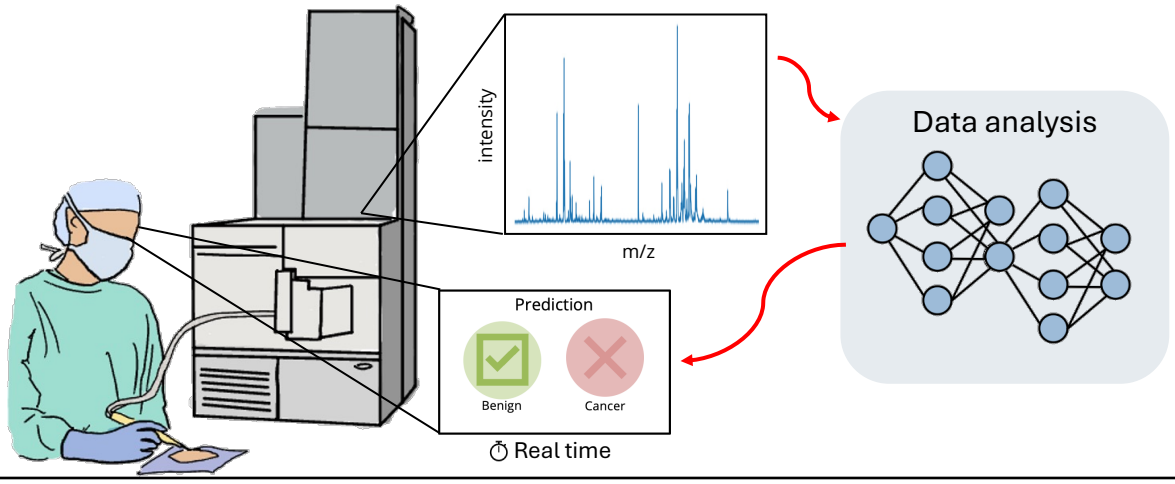
Mass spectrometry imaging

Intraoperative margin evaluation with mass spectrometry imaging



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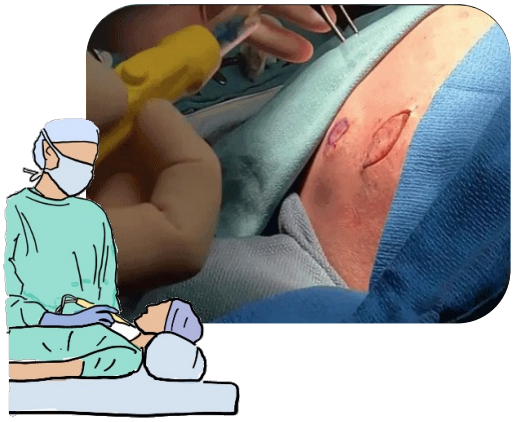
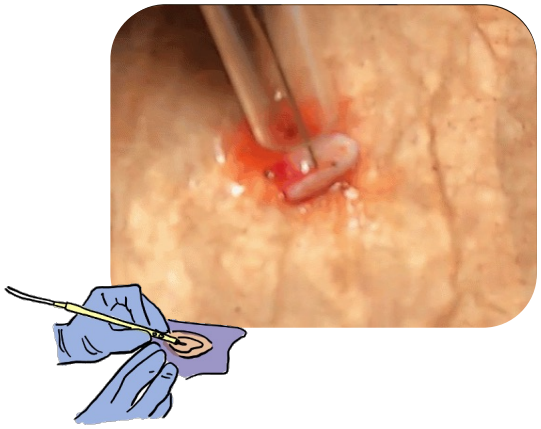
Data

In vivo data
10 407 spectra, 43 resections



Ex vivo data
693 spectra (252 BCC, 441 benign), 91 patients



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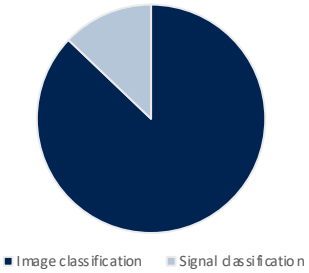
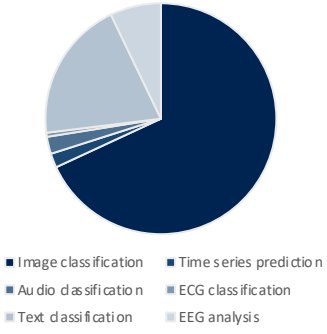
Motivation

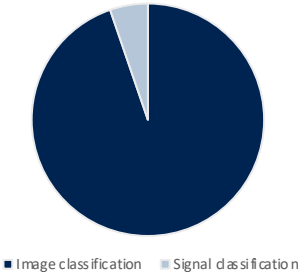
Search results on Google Scholar

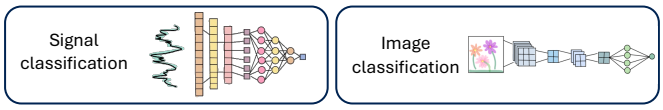


State-of-the-art on Papers with Code



Available Datasets on Kaggle





Updated on May 8th, 2024

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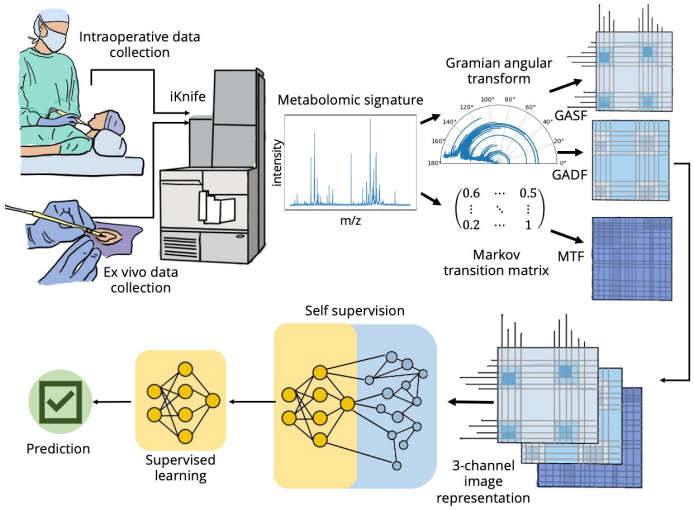
Methodology

Scan for paper

- Technical challenges: real-time data analysis, out of distribution or noisy data, intraoperative deployment
- Leveraged self-supervised learning and image-conversion to improve iKnife classification models



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Results

Scan for paper

	Method	Pretrain	Train	Balanced accuracy	Sensitivity	Specificity	AUC
Signal (1D)	ML	None	exvivo	69.7±2.3	66.0±3.3	73.5±1.7	73.9±1.3
	MLP	None	exvivo	73.8±2.4	59.4±5.4	88.2±3.8	78.6±2.0
	BNN	None	exvivo	72.1±1.8	60.5±3.7	83.7±2.7	81.1±2.3
Image (2D)	Imspect (ours)	None	exvivo	70.4±2.2	57.2±5.0	83.4±2.7	75.9±1.4
		exvivo	exvivo	66.4±2.1	58.4±3.0	74.6±4.0	74.5±1.7
		ImageNet	exvivo	72.0±2.7	63.5±1.7	80.5±3.0	77.8±1.7
		exvivo + intraop	exvivo + intraop	72.1±2.0	66.0±5.8	77.9±5.2	80.1±1.8
		exvivo + intraop	**exvivo**	73.5±1.4	63.1±2.6	83.9±1.8	81.6±1.4

49

Results

Scan for paper

	Method	Pretrain	Train	Balanced accuracy	Sensitivity	Specificity	AUC
Signal (1D)	ML	None	exvivo	69.7±2.3	66.0±3.3	73.5±1.7	73.9±1.3
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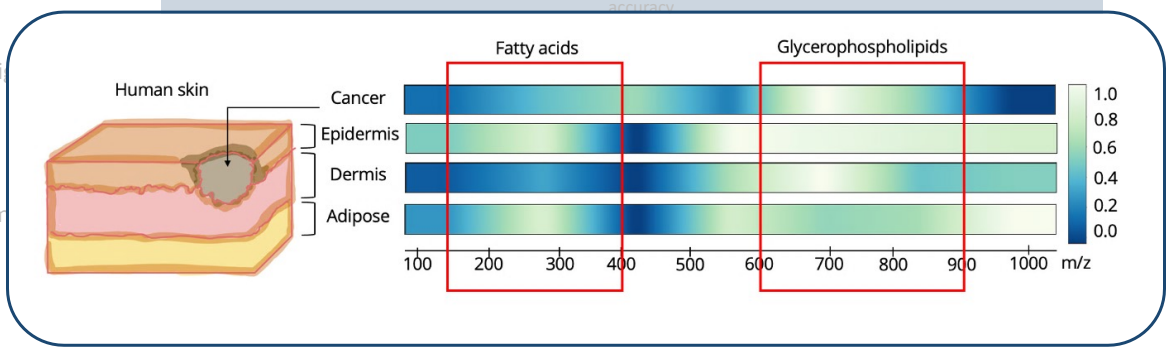
		exvivo	exvivo	66.4±2.1	58.4±3.0	74.6±4.0	74.5±1.7
		ImageNet	exvivo	72.0±2.7	63.5±1.7	80.5±3.0	77.8±1.7
		exvivo + intraop	exvivo + intraop	72.1±2.0	66.0±5.8	77.9±5.2	80.1±1.8
		exvivo + intraop	**exvivo**	73.5±1.4	63.1±2.6	83.9±1.8	81.6±1.4

50

Results

Scan for paper



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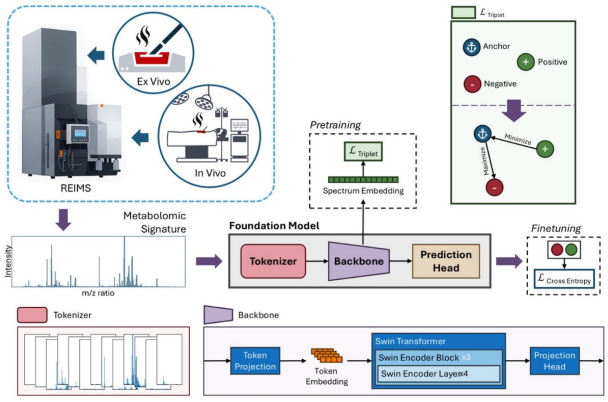
Limitations and ongoing work

- Limited number of patients and samples, should be extended to a larger dataset
- Translate from surrogate tissue dataset to breast tissue
- Explore how these representations can be used for new foundation models

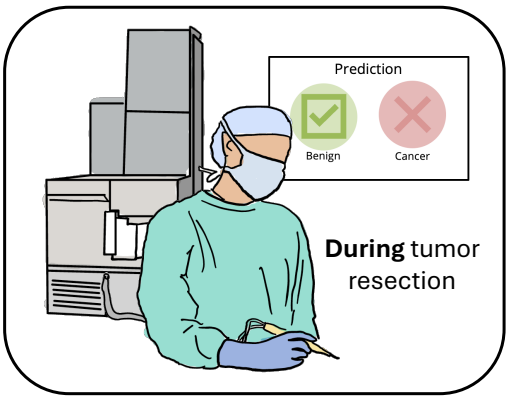


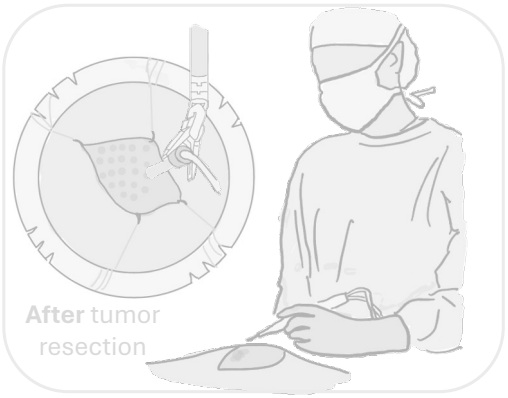
Scan for paper

52

Objectives

Investigate how robotics, tissue sensing, and AI can be used to <u>prevent positive margins</u> in BCS





53

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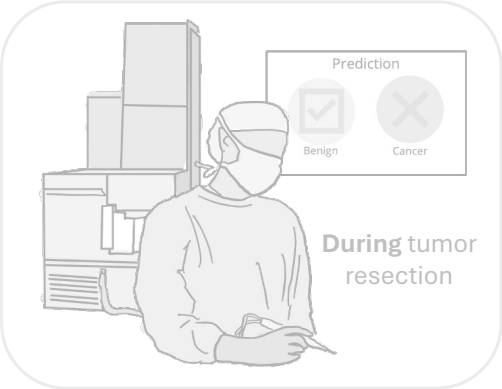

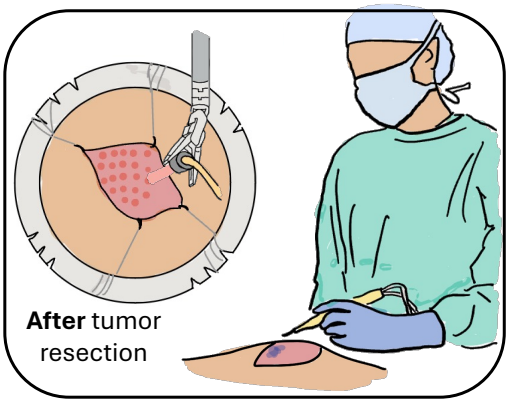

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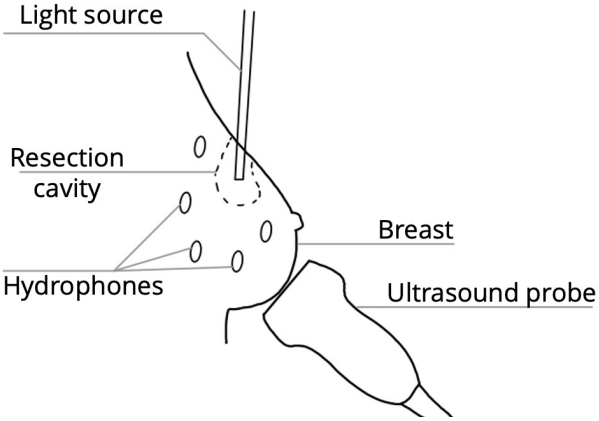
Photoacoustic tumor bed inspection

- **Photoacoustic imaging:** Pulses of laser light are used to induce localized, optical absorption-based thermal expansion
- **Contrast agents** that are PA sensitive can be used to target specific tissue



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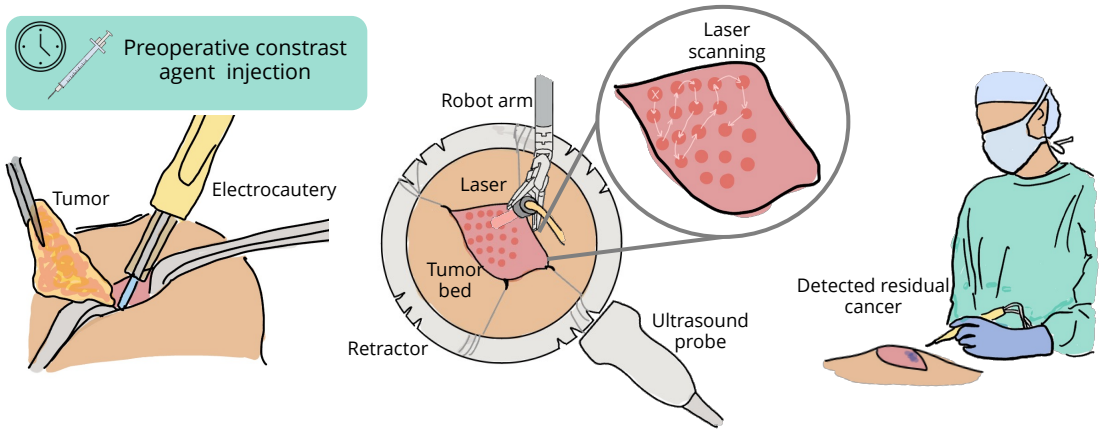
Photoacoustic tumor bed inspection



56

Tumor bed models

3 different cavity geometries for evaluation

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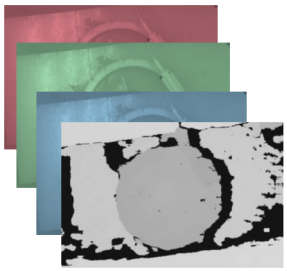
Tumor bed inspection

Part 1: Cavity sensing



Part 2: Registration

Part 3: Scanning

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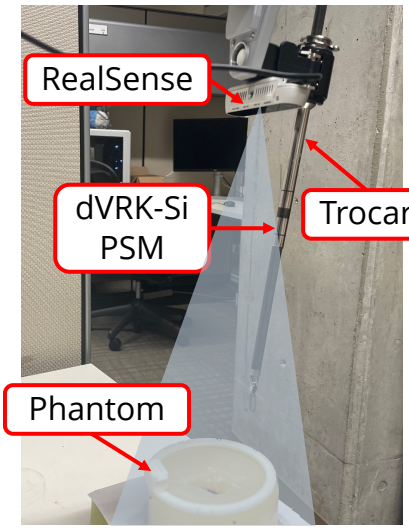
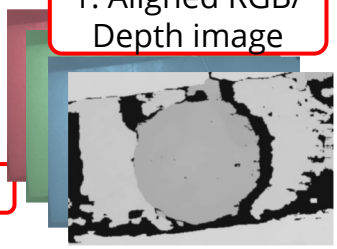
Cavity sensing



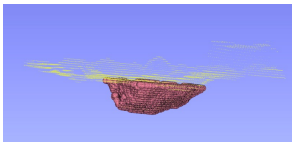
1. Aligned RGB/ Depth image



2. Retractor detection

3. Label mask / depth filter

4. Point cloud / scanning path



https://github.com/PerkLab/DepthImageToPointCloud

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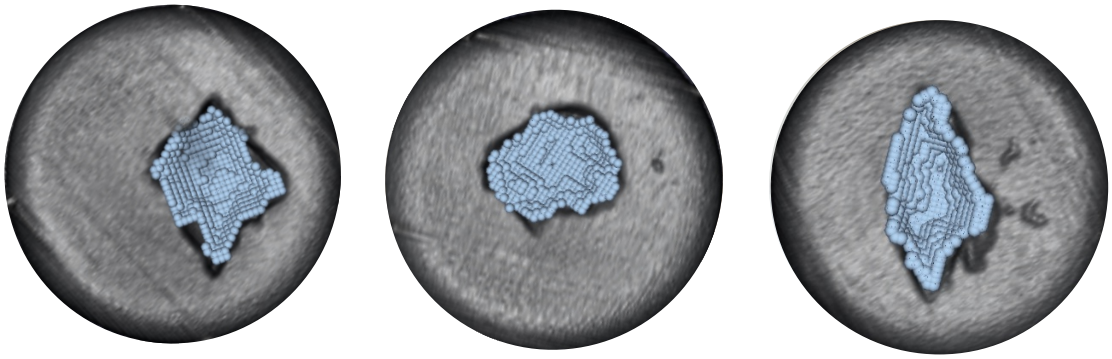
Cavity sensing

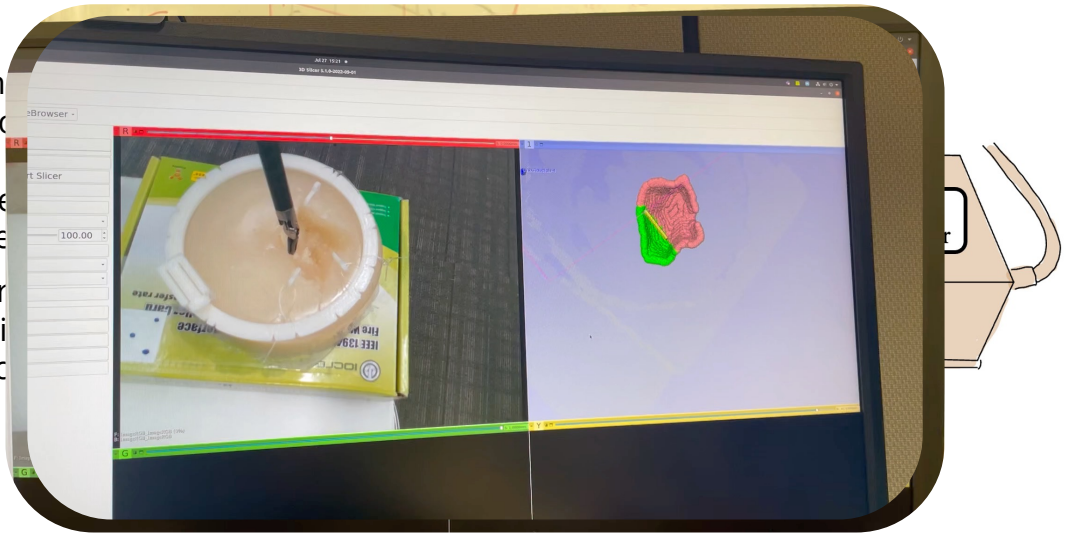


Sensed cavities on tumor bed (overlaid on volume reconstruction of CT)

60

Registration

- Track th
  point cl
  relative
  sensor e
  in the re
- Register
  everythi
  robots c
  system



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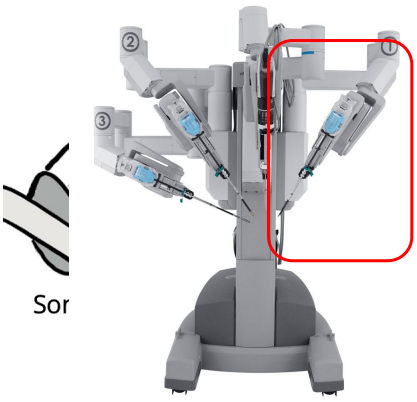
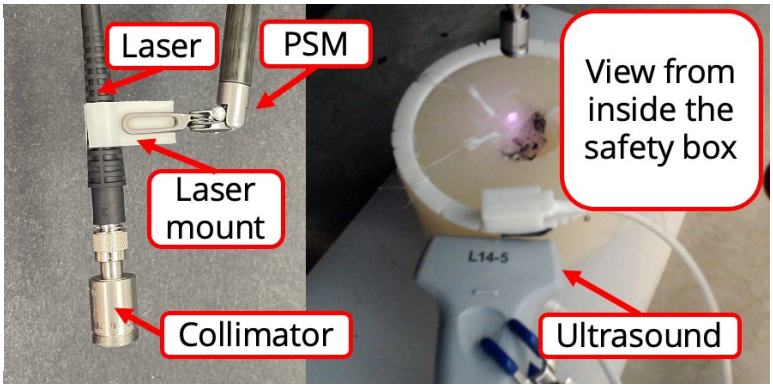
Scanning

Paper in review





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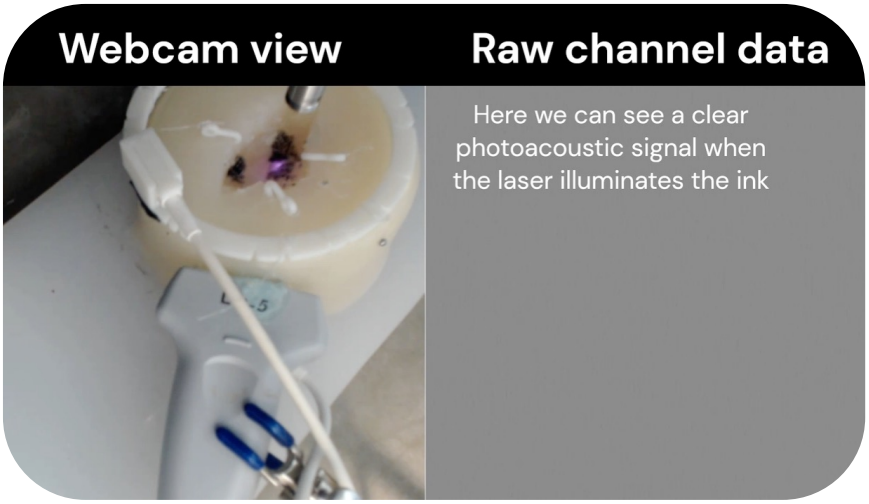
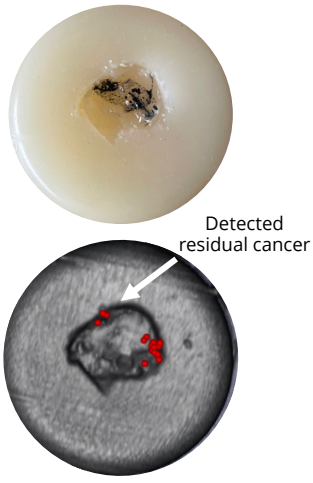
Results

Paper in review





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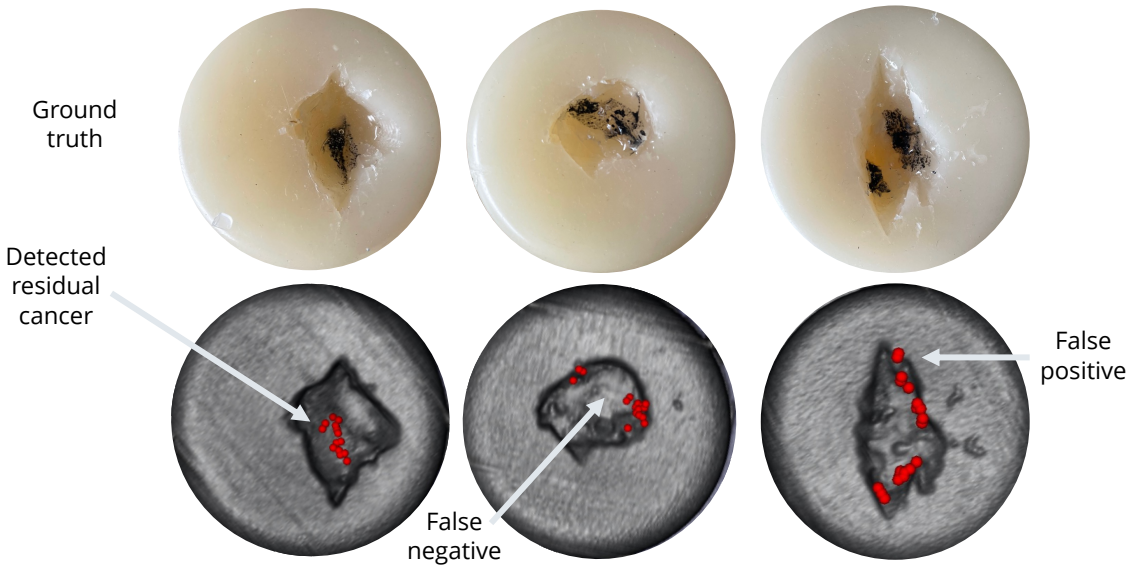
Results

Paper in review



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Limitations and ongoing work

Scan for paper

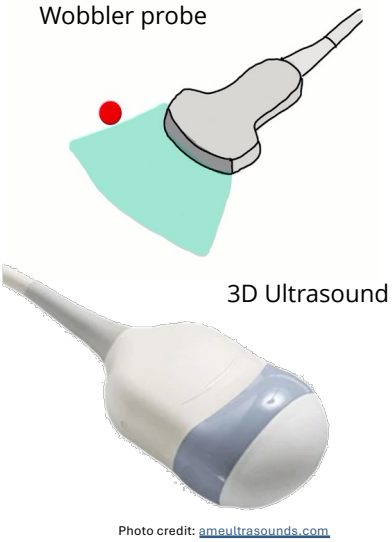
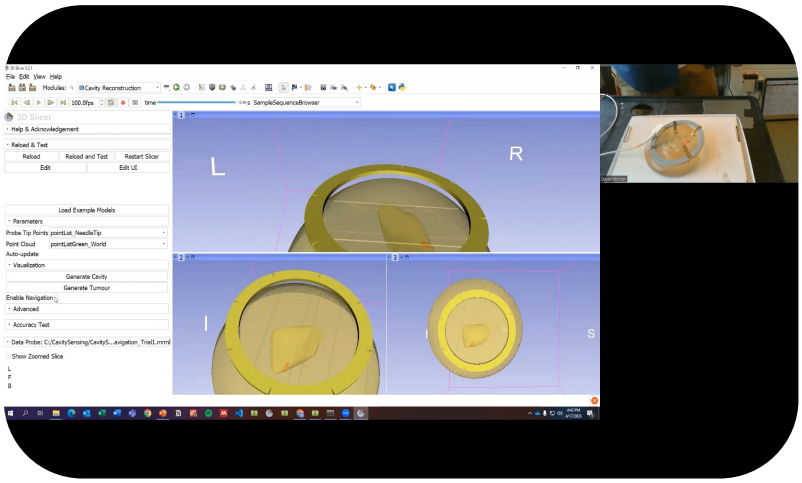


Photo credit: ameultrasounds.com



65

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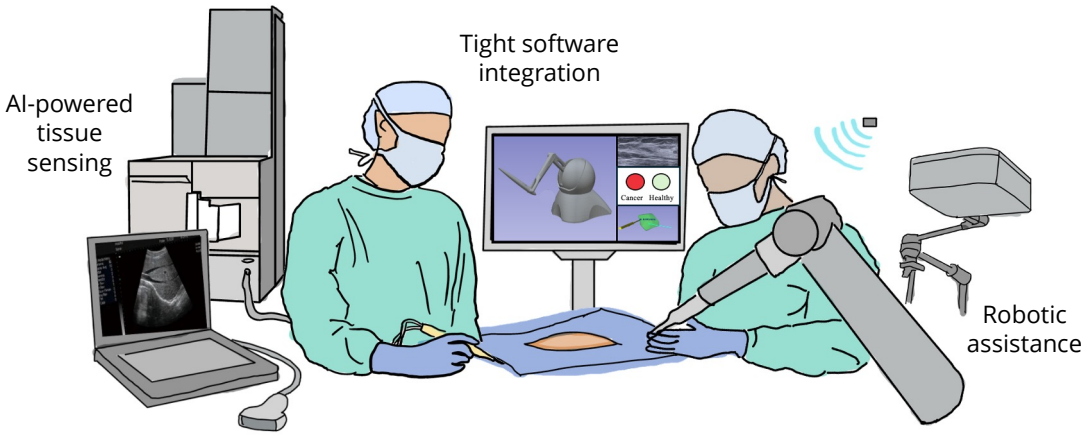
Investigate how robotics, tissue sensing, and AI can be used to <u>prevent positive margins</u> in BCS



66

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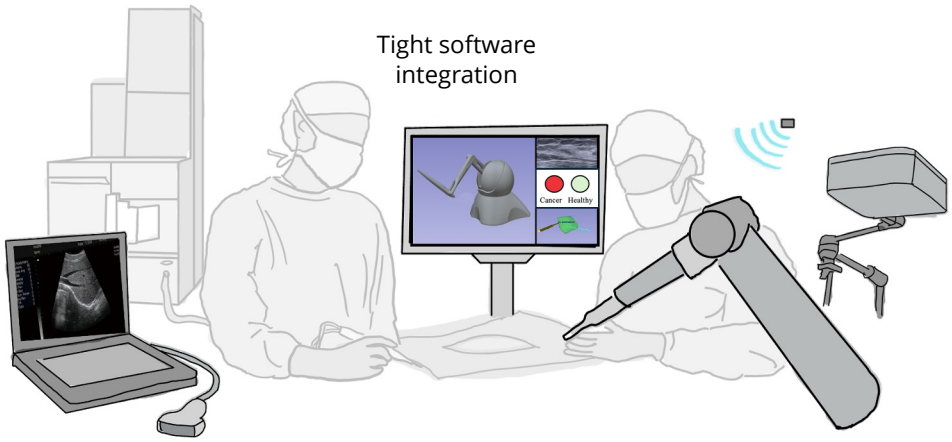

67

Image-guided robotics

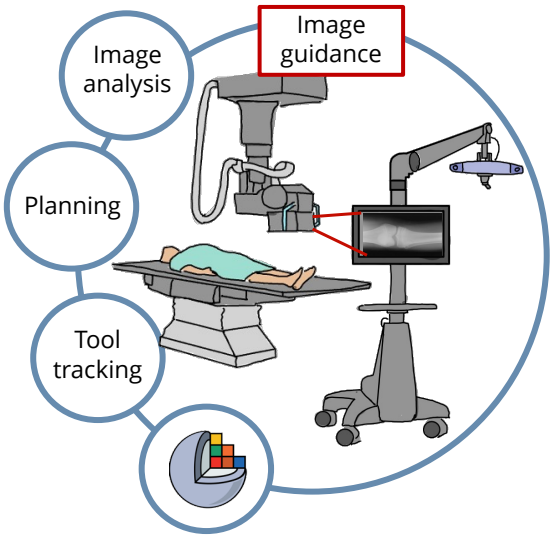

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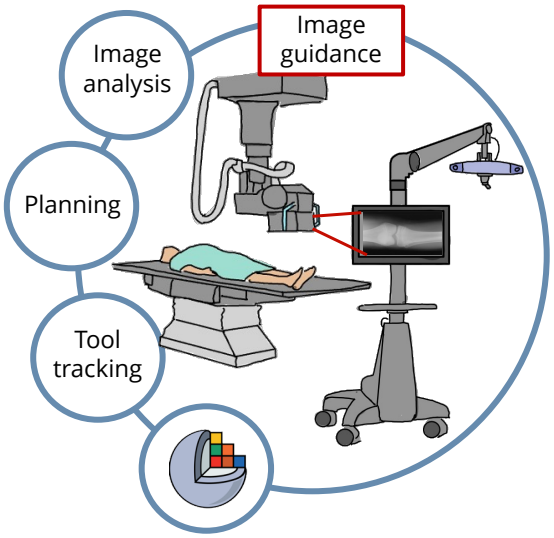
Image-guided robotics



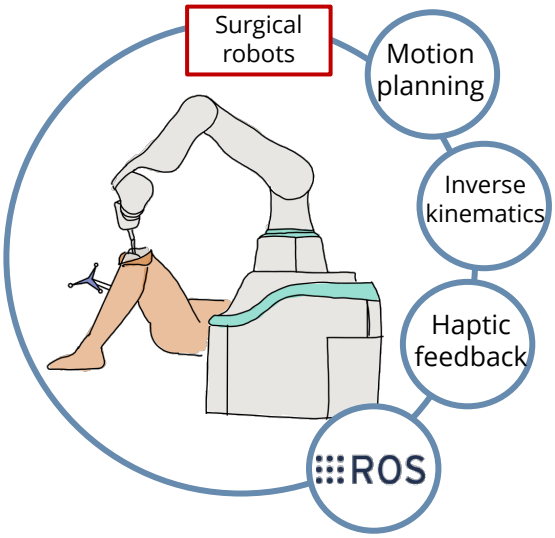


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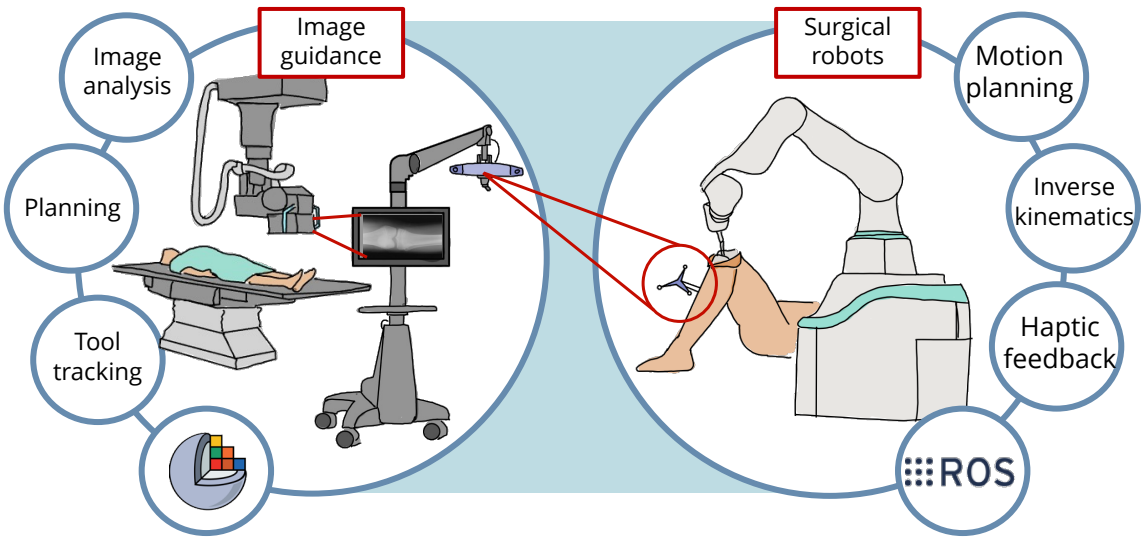
Image-guided robotics



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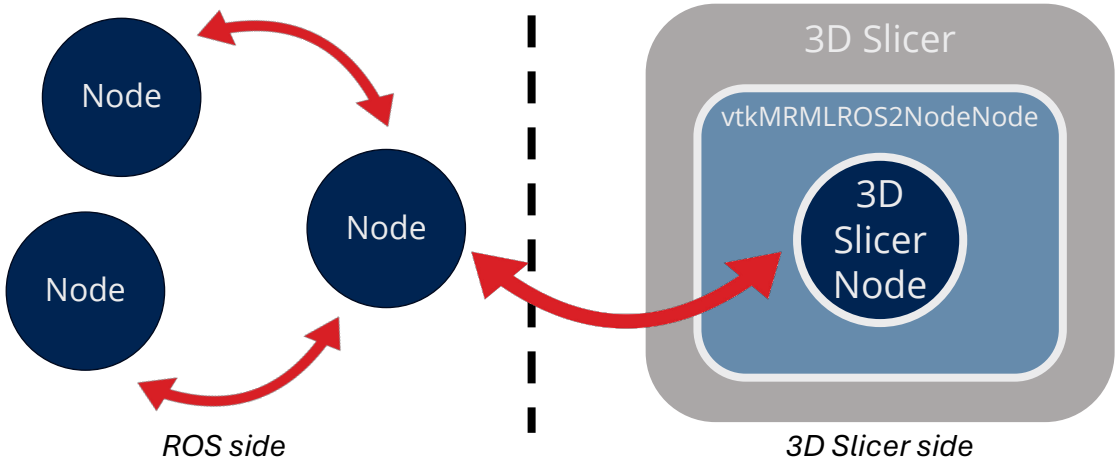
Methodology

3D Slicer is treated like a ROS Node

ROS communication mechanisms are packages as Slicer MRML Nodes



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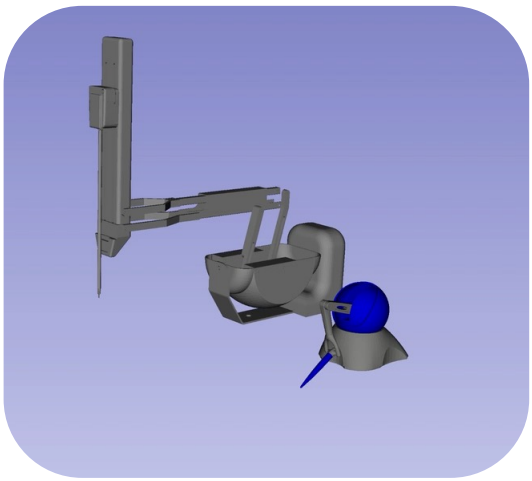
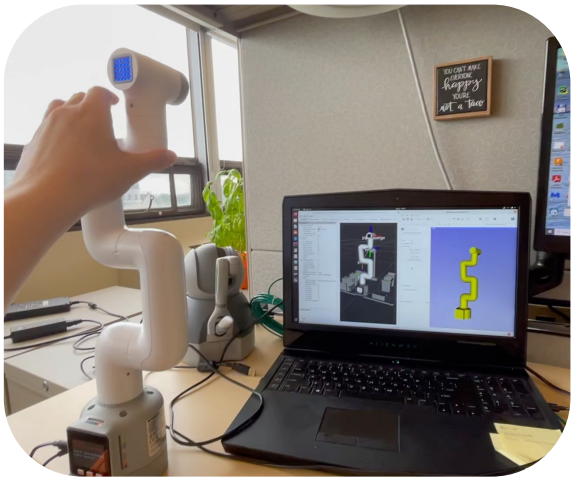
Results - SlicerROS2

Scan for paper

Load and visualize ROS2 compatible robots





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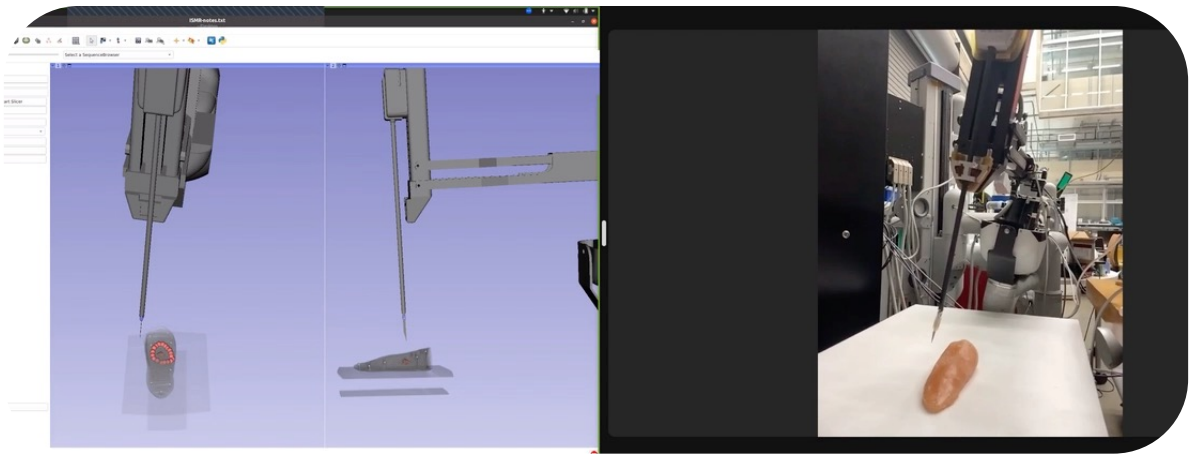
Results - SlicerROS2

Scan for paper

Register medical images and robots



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Results - SlicerROS2

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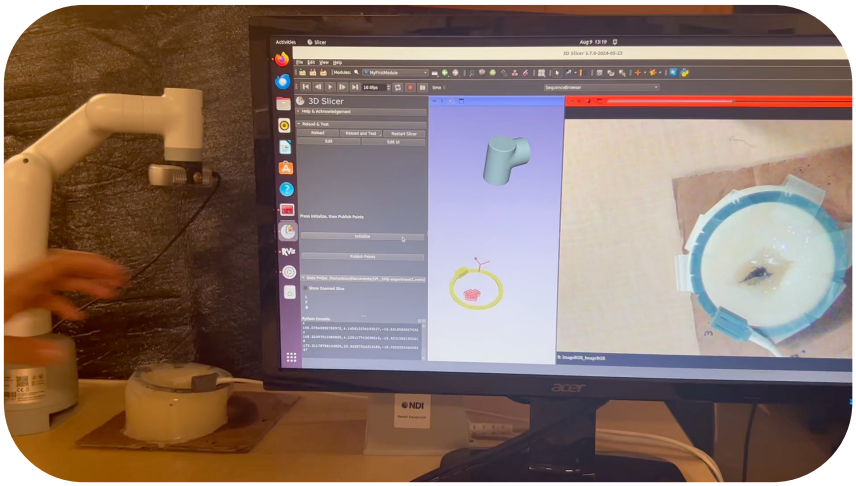
Integrate with tracking systems



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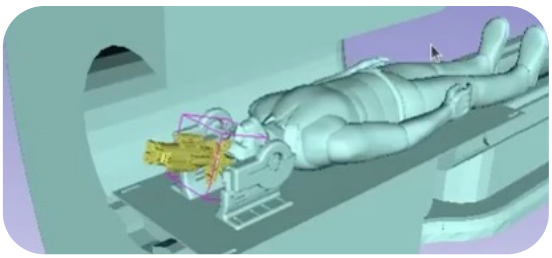
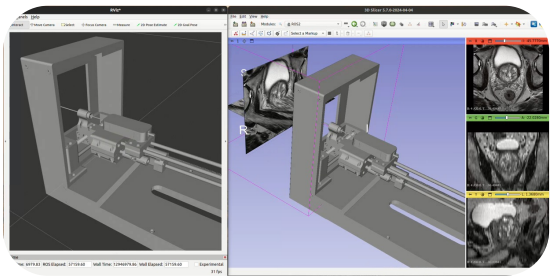
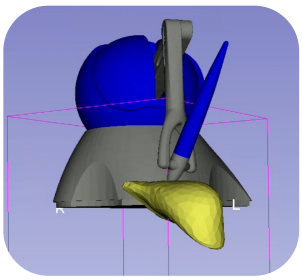
Preliminary user-base and future potential





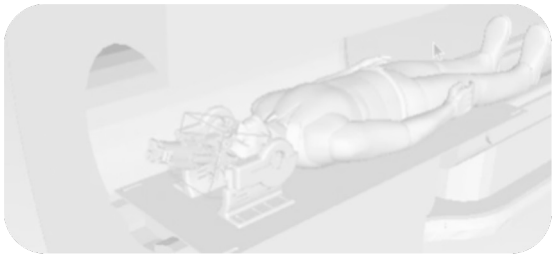


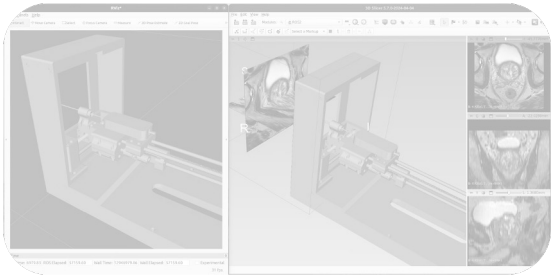
- *Brigham and Women's Hospital, Boston, USA*
- *Oslo University Hospital, Oslo, Norway*
- *University of Texas at Austin, Texas, USA*
- *Georgia Institute of Technology, Atlanta, USA*
- *Johns Hopkins Univeristy, Baltimore, USA*

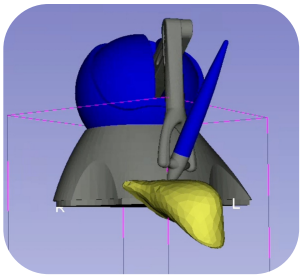
37 stars
3 watching
6 forks

75

Preliminary user-base and future potential







- *Brigham and Women's Hospital, Boston, USA*
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- *Georgia Institute of Technology, Atlanta, USA*
- *Johns Hopkins Univeristy, Baltimore, USA*

...and growing!

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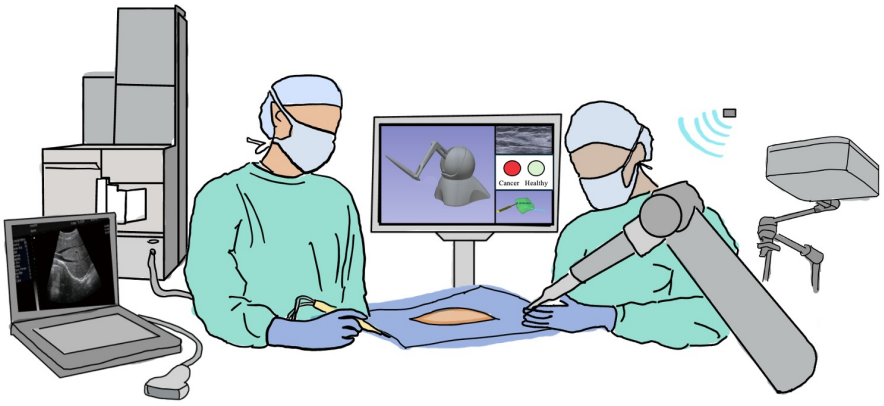
Conclusions and summary

- Preliminary results for margin prevention are encouraging
- Future work will include translation efforts, simplifying systems for clinical translation, and discussions with surgeons on the most effective embodiments



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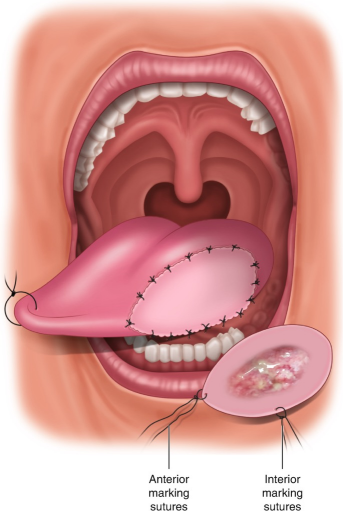
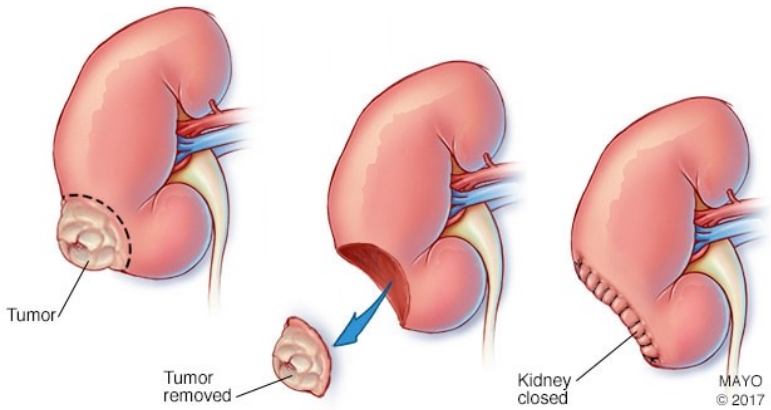
Future work



Transoral Partial Glossectomy, Atlas of Head and Neck Surgery.

What other procedures may benefit from this technology?



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Acknowledgments

Queen's UNIVERSITY

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Thank you for your attention!

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Walter C. Sumner Memorial Foundation

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NSERC Med-i CREATE Training Program in Medical Informatics

NSERC Michael Smith Foreign Study Supplement

Mitacs Globalink Research Program

Canadian Institutes of Health Research (CIHR)

NIH R01EB020667 and 3R01EB020667

Queen's Tri-Agency Recipient Recognition Award (TARRA)

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