3D Ultrasound for prostate, GYN, and breast brachytherapy

Aaron Fenster, Jessica Rodgers, Justin Michael, Tom Hrinivich

July 15 , 2019

Why 3D Ultrasound ?

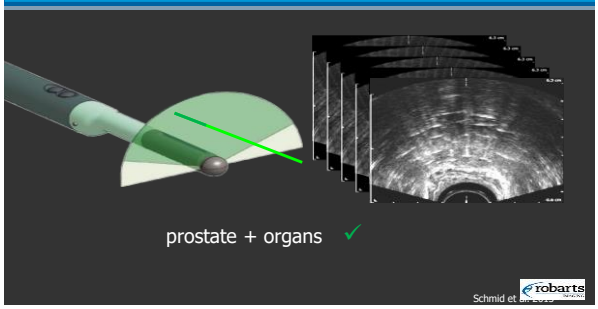
- Improved appreciation of 3D anatomy
- Improved ability to verify brachytherapy needle locations
- More accurate volumetric measurements
- Reduce variability and time of 2D US guidance and verification
- Improved brachytherapy procedure

3D Ultrasound–guided Brachytherapy Developments

- **Prostate HDR brachytherapy**
- **Gynecologic interstitial HDR brachytherapy**
- **Breast LDR brachytherapy**

Hrinivich WT, Hoover DA, Surry K, Edirisinghe C, Montreuil J, D'Souza D, **Fenster A**, Wong E. *Three-dimensional transrectal ultrasound guided high-dose-rate prostate brachytherapy: a comparison of needle segmentation accuracy with two-dimensional image guidance.* Brachytherapy. 15(2): 231-239, 2016.

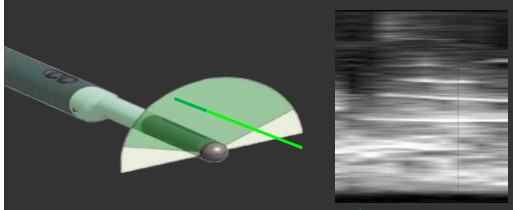
Current practice: axial 3D ultrasound



prostate + organs ✓

Schmid et

Current practice: axial 3D ultrasound

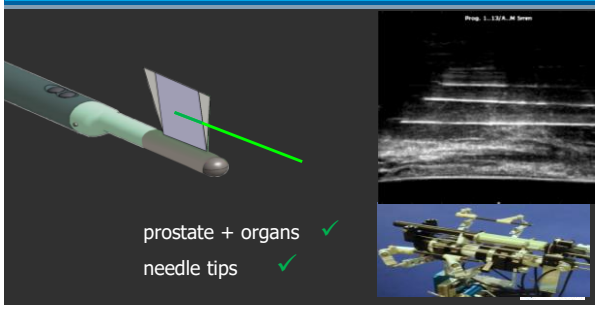


prostate + organs ✓

needle tips ✗

Schmid et

Current practice: live 2D ultrasound



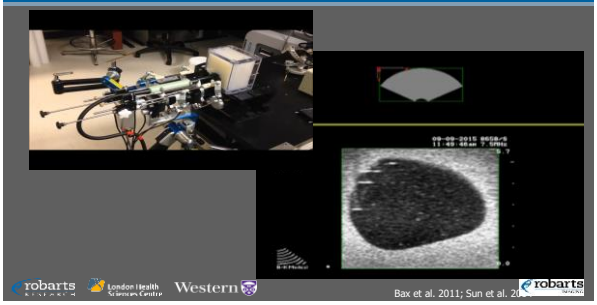
prostate + organs ✓

needle tips ✓

Objective

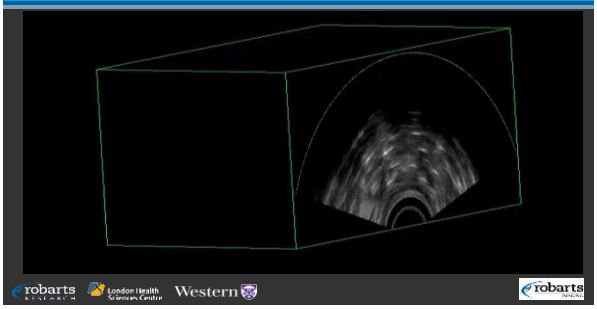
Reduce needle tip localization uncertainty by replacing axial 3D ultrasound with sagittal 3D ultrasound

Sagittal 3D ultrasound

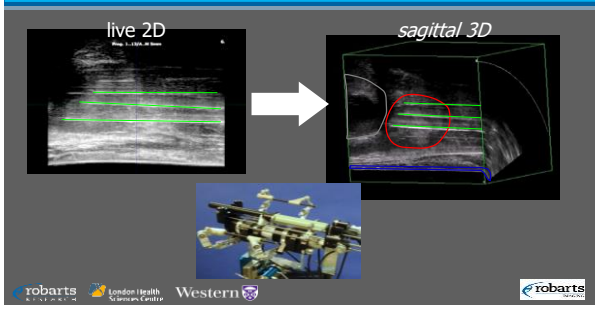


Bax et al. 2011; Sun et al. 20

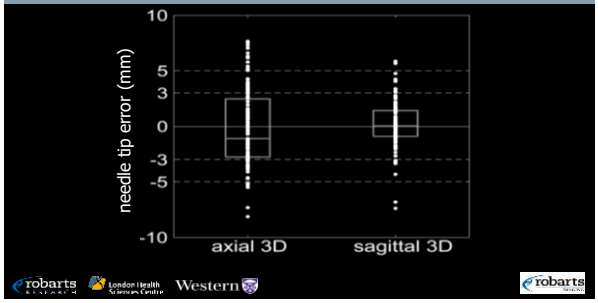
sagittal 3D ultrasound



New technique: live 2D + sagittal 3D



Results: 8 patients, 127 needles



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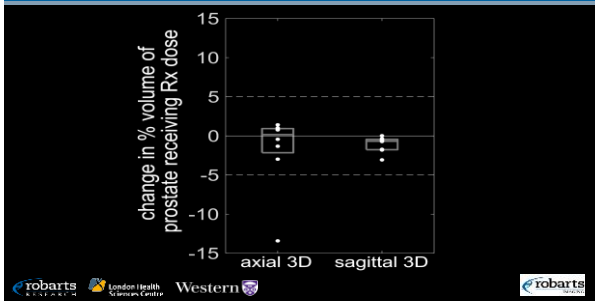

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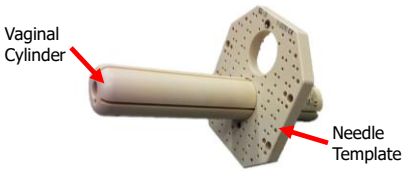
- **Gynecologic interstitial HDR brachytherapy**
- Breast LDR brachytherapy

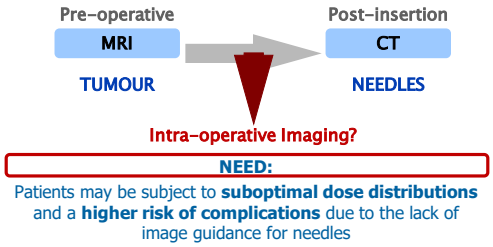
- **More information: YIS J. Rodgers at 2:09pm**

High-Dose-Rate (HDR) Interstitial Brachytherapy

- Needles inserted into tumour and surrounding area
  - Through the perineal template
  - Radioactive source is inserted into needles



Gynaecologic Brachytherapy Imaging



Objective

To develop a **3D ultrasound** (3DUS) needle guidance system for high-dose-rate interstitial brachytherapy of gynecologic cancers, which will provide accurate intra-operative assessment of implant

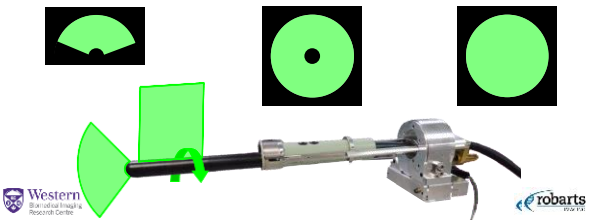
3D US Imaging Device

3 modes

170° 3D **sidefire transrectal** US (TRUS)

360° 3D **sidefire transvaginal** US (TVUS)

3D **endfire TVUS**



Vaginal Cylinder

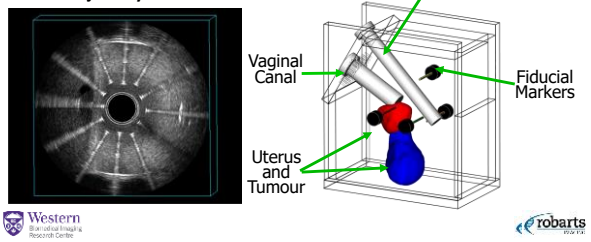
Solid Clinical Cylinder

Hollow TPX Cylinder

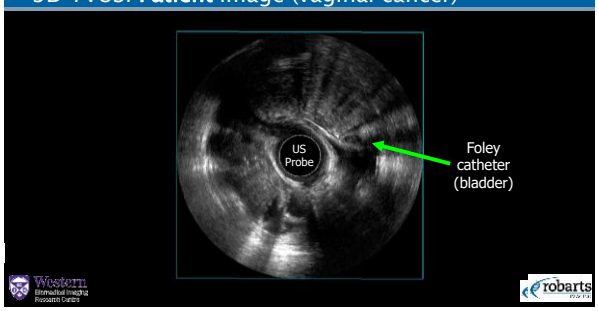
Real-Time 3D US Image Reconstruction

Pelvic Phantom Study – compared to CT

Mean tip difference: 1.84 ± 0.42 mm
Mean trajectory difference: 0.40 ± 0.35°



3D TVUS: **Patient** image (vaginal cancer)



3D TVUS: **Patient** image (vaginal cancer)

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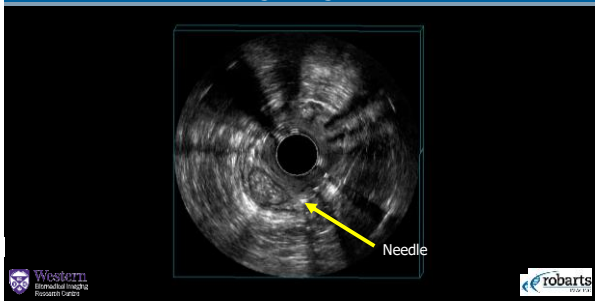

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- **Gynecologic interstitial HDR brachytherapy**
- **Breast LDR brachytherapy**
  - ✓ Together with Kelowna, Canada group

Michael J, Morton D, Batchelar D, Hilts M, Crook J, Fenster A. *Development of a 3D Ultrasound Guidance System for Permanent Breast Seed Implantation.* Medical Physics, 45(8) 3481-3495, 2018.

Limitations of current breast LDR brachytherapy

- High operator dependence using 2D US
  1. Requires experienced physician with use of ultrasound
  2. Deformable tissue with few landmarks
  3. Limited information to modify 3D radiation plan

Image from Pignol et al. 2006, Int J Radiat Oncol Biol Phys

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Objective

To develop a 3D US guidance and needle template tracking to reduce operator dependence of PBSI by:

1) Improving needle visualization

2) Improving needle placement accuracy

3) Providing information to modify treatment plan intraoperatively

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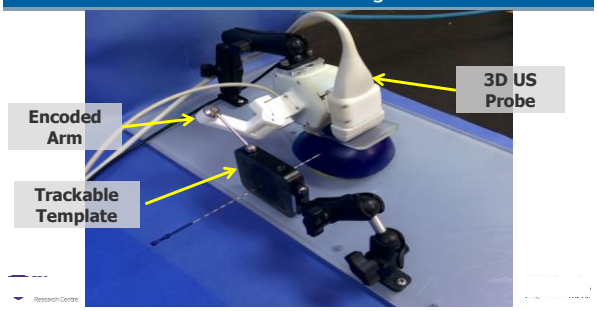
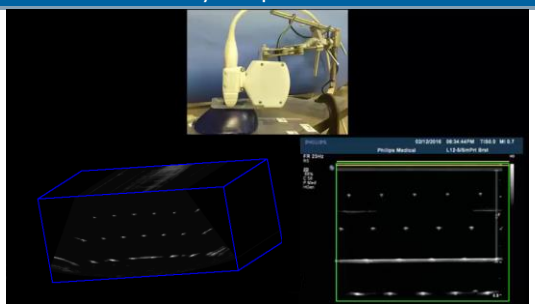
3D US with Mechatronic Tracking



3D US: Mechanically Swept 2D Transducer

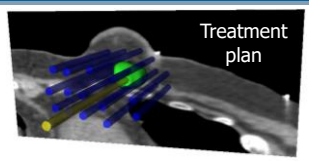


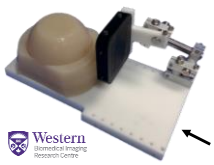
3D US image of volunteer

- Validated linear, volumetric accuracy (±1.1%, ±4.1% respectively)
- Pilot study scanning healthy female volunteer
  - Positive feedback on device usability and image quality

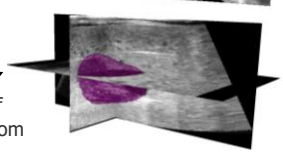
Guiding a Phantom Procedure

- Agar phantom with "seroma" matching patient contours
- Surface based registration between 3DUS, matching treatment plan





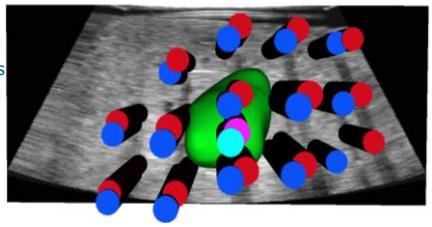
3D US of agar phantom



Guiding a Phantom Procedure

- Planned Needles
- Planned Fiducial
- Observed Needles
- Planned Fiducial

Tip Error:
2.43 ± 1.4 mm
Trajectory Error:
1.22 ± 0.59°



Summary

- Mechanical 3DUS **not subject to environmental constraints**
- Accurate assessment of **needle trajectory in 3D**
- Visualize needles in **all template areas**
- Approaches compatible with all **conventional US** systems

Thank You

Graduate Students, Post-docs
Jessica Rodgers, Derek Gillies, Tom Hrinivich, Eric Knull, Nathan Orlando, Claire Park, Priyanka Roy

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Collaborating Scientists
Terry Peters, Aaron Ward, Mingyue Ding, Kathleen Surry, Deidre Batchelar, Michelle Hilts, Tyler Meyer, Michael Roumeliotis

Collaborating Physicians
David D'Souza, Lucas Mendez, Glenn Bauman, Eric Leung, Vikram Velker, Juanita Crook

3D US Imaging Device

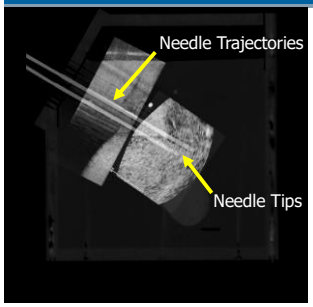
3 modes

170° 3D **sidefire transrectal** US (TRUS)

360° 3D **sidefire transvaginal** US (TVUS)

3D **endfire TVUS**

Combined 3D Sidefire and **Endfire** TVUS (**Phantom**)



Mean Needle Tip Difference: 1.91 ± 0.24 mm

Mean Angular Difference: 1.51 ± 0.81 °