NAVIGATION IN BRACHYTHERAPY

Challenge #1: **Data Acquisition**
- Fast, practical, accurate

Challenge #2: **Quality Assurance**
- Enhanced independent plan check

Challenge #3: **Automatic Digitization**
- A tricky registration problem

Challenge #4: **Adaptive Therapy and Navigation**
- Implant displacement, deformation, etc.

Antonio L. Damato, PhD

DISCLOSURES

- Travel grant from Elekta (2015) related to electromagnetic tracking
- Some devices discussed in this talk are not FDA approved

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OPTICAL NAVIGATION SYSTEMS

http://bluebelttech.com/

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ELECTROMAGNETIC TRACKING

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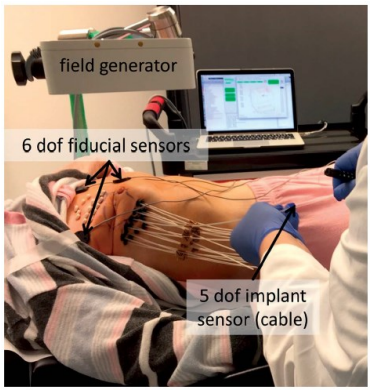
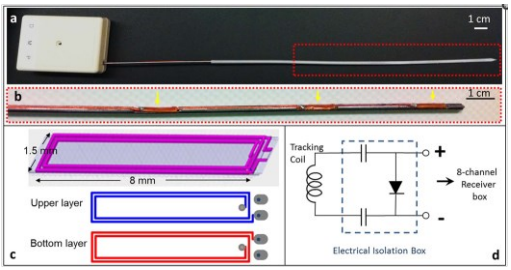


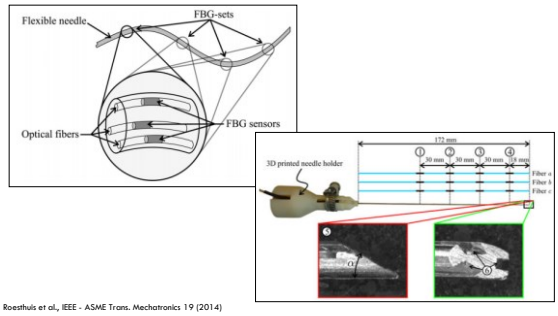
Bert et al., J Contemp Brachytherapy2016

ACTIVE MR TRACKING



Wang et al., Magn Reson Med. 2015 May; 73(5):1803-11

FIBER BRAGG GRATING



Roesthuis et al., IEEE - ASME Trans. Mechatronics 19 (2014)

TRACKING: DATA QUALITY

Summary: **Data acquisition**

Accurate, fast data acquisition is possible:

- Manual data acquisition is possible
- For some applications, for some technologies, robotic delivery is advantageous

Evaluating a tracking system / application:

- Practical / safety considerations
- Evaluation of noise / error (average, max)
- Noise / error in clinical practice
- Absolute vs. relative registration

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TRACKING FOR QUALITY ASSURANCE

Quality item	Detectability			EMT coordinate system	Error probability and effect [23]	
	IVD	Imaging	EMT		Probability of error	Effect
Source calibration	✓	✗	✗	–	Low	Low-high
Afterloader source positioning and dwell time (non-patient specific)	✓	✗	(✓)	E	–	–
Afterloader malfunction	✓	✗	(✓)	E	Low	Low-high
Patient identification	✗	✓	(✓)	E/F	Low	High
Correct treatment plan	✓	✗	✓	E	Low	High
Intra- and interfraction organ/applicator movement	✓	✓	✓	E/F/A	–	–
Applicator reconstruction	✓	✓	✓	E	Intermediate	Low-intermediate
Applicator length/source indexer length	✓	✗	✓	E/F	Intermediate	Low-high
Source step size (patient specific)	✓	✗	✓	E	Low	High
Interchanged guide tubes	✓	✗	✓	E/F	Intermediate	Low-high
Recording of dose	✓	✗	✗	–	–	–

Bert et al.; *J Contemp Brachytherapy* 2016

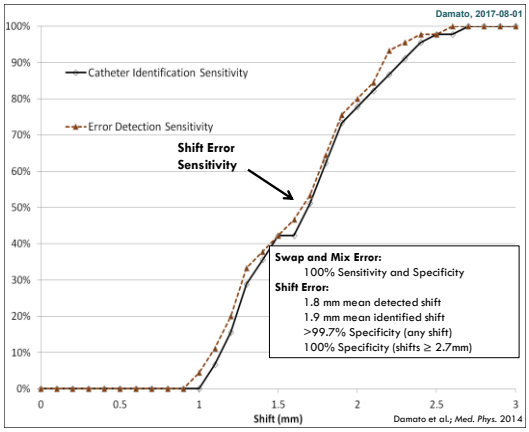
TRACKING FOR QUALITY ASSURANCE[1]

Challenge: Digitization QA

Catheter digitization performed manually:
- Based on visibility in CT, MR or US, which may be poor
- FMEA[2]: detection of errors "unlikely"
- FMEA[2]: high risk-priority number
- 20% of medical events (NRC) related to digitization

Goals:
- Tracking for digitization QA
- Tracking for treatment verification

[1] Damato et al.; *Med. Phys.* 2014 [2] Wilkinson et al.; *Brachytherapy* 2013



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EM TRACKING FOR QUALITY ASSURANCE

Summary: **Digitization QA**

Enhanced plan QA possible:

- Low noise (0.6 mm), low offset (< 0.6 mm) data
- 100% specificity/sensitivity
- Can be expanded to catheter length / attachment checks

Clinical validation underway (mostly EM):

- Phantom experiments
- Preliminary: gynecologic brachytherapy
- Prostate brachytherapy
- Breast brachytherapy

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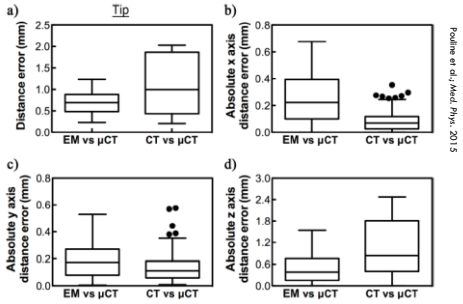
EM TRACKING FOR AUTOMATIC DIGITIZATION



Poulin et al.; *Med. Phys.* 2015

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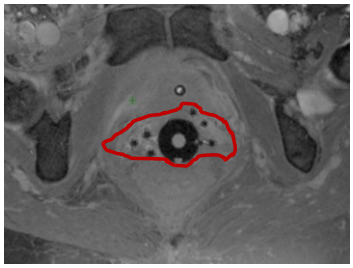
REGISTRATION MATTERS



Tracker accuracy:
- < 1mm average
- > 1mm maximum

Total accuracy:
- Simulations in phantoms
- Initial work on clinical validation
- External fiducials
  - 3-4 mm average
  - 5-6 mm maximum
  - unreliable

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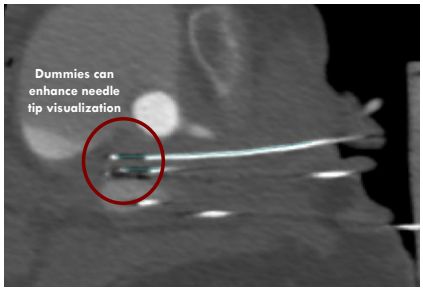
ALTERNATIVE APPROACH: SEMI-AUTOMATIC DIGITIZATION



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EM TRACKING FOR AUTOMATIC DIGITIZATION IN TRUS

Calibration in low distortion environment

In-plane discrepancy (mm)			Out-of-plane discrepancy (mm)		
Mean	Standard deviation	Maximum	Mean	Standard deviation	Maximum
0.4	0.2	1	0.8	0.4	1.7
1	0.2	1.5	1.1	0.8	1.9
0.3	0.2	1.1	1.1	0.8	1.9
0.6	0.3	1.5	0.4	0.2	0.6

Bharat et al., *Brachytherapy*, 2016

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EM TRACKING FOR AUTOMATIC DIGITIZATION IN TRUS

Updated calibration in distorting environment

In-plane discrepancy (mm)			Out-of-plane discrepancy (mm)		
Mean	Standard deviation	Maximum	Mean	Standard deviation	Maximum
0.4	0.2	1	0.8	0.4	1.7
1	0.2	1.5	1.1	0.8	1.9
0.3	0.2	1.1	1.1	0.8	1.9
0.6	0.3	1.5	0.4	0.2	0.6

Bharat et al., *Brachytherapy*, 2016

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EM TRACKING FOR AUTOMATIC DIGITIZATION

Challenge: **Automatic Digitization**

Registration of EM and CT/MR frame-of-reference:

- All dwell positions: for QA only
- External markers: less precise, unreliable
- A priori-registration: unfeasible
- User input required

Goals:

- Fast, accurate catheter digitization
- Minimal user intervention

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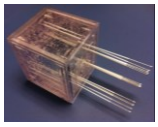
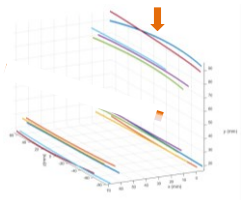
Catheter Trajectory Reconstruction by MR Tracking

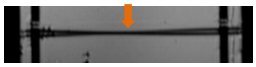
Phantom Study





Fifteen needles: 9 parallel + 3 pairs crossed
Through two templates with 5 mm grid of holes

A. MR-image based needle digitization
B. Active Tracking during stylet pull-out



3D MP-RAGE, resolution: 0.5 × 0.5 × 1 mm^3

Two bent needles

Two crossed needles

Wang et al., *Magn Reson Med*. 2014

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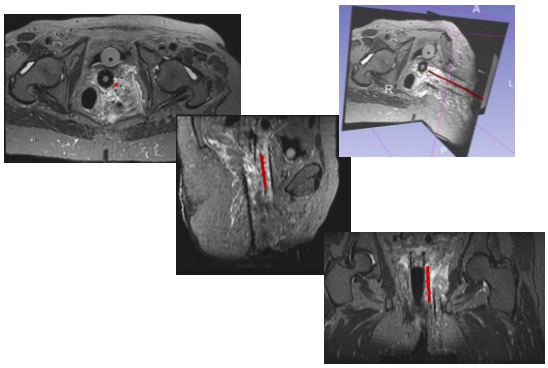
Catheter Trajectory Reconstruction by MR Tracking



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MRI TRACKING FOR AUTOMATIC DIGITIZATION

TABLE II. Comparison between MRTR-generated catheter trajectories and the image-based digitization (CT and MRI). Equally spaced dwell positions were generated along each trajectory by interpolation, and the corresponding dwell points from the different methods were compared. d_x, d_y, and d_z represent differences along each axis. d_{3D} represents the 3D distance between corresponding dwell points.

Wang et al., *Med. Phys.* 2016

	d_x (mm)	d_y (mm)	d_z (mm)	d_{3D} (mm)
MRTR vs MRI	0.3 ± 0.4	−0.1 ± 0.2	1.3 ± 0.5	1.5 ± 0.7
MRTR vs CT	0.4 ± 0.2	−0.6 ± 0.2	0.2 ± 0.6	0.7 ± 0.4

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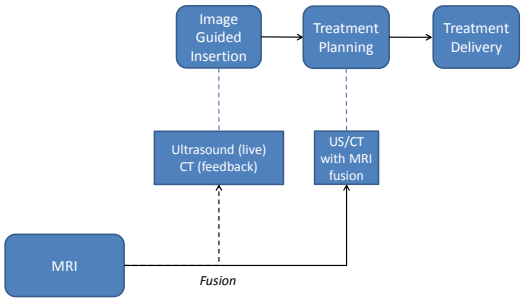
MRI-Assisted Workflow



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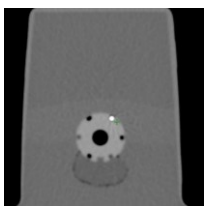
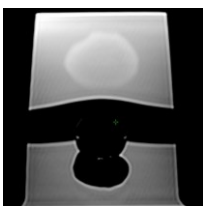
End-to-end phantom experiment



CT: implant identification



MR: tumor identification

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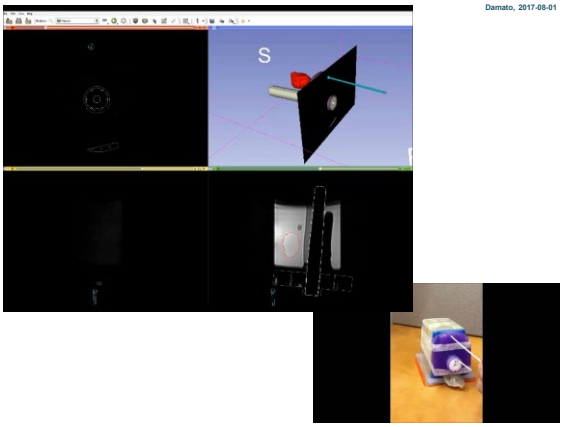

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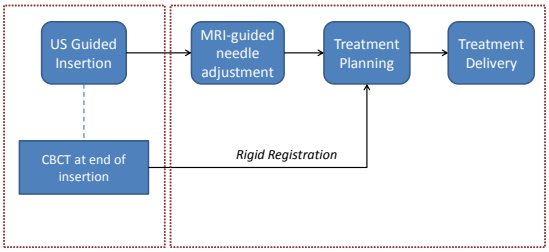
MSKCC MRI-Guided Workflow



Brachy Suite MRI dockable tabletop

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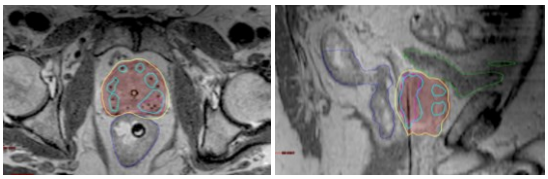
MSKCC MRI-Guided Workflow



Memorial Sloan Kettering Cancer Center

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Utrecht MRI-Guided Workflow

1. Diagnostic MRI.	• Used for contouring of prostate, tumor and OAR's.
2. Ultrasound	• Rigid registration to 1. • Used to guide catheter placement.
3. Intraoperative MRI before treatment. (pre-treatment)	• Rigid registration to 1. • Used for treatment planning.
4. Intraoperative MRI before HDR delivery.	• Rigid registration to 3. • Used to check the cathether position.
5. Intraoperative MRI after HDR delivery. (post-treatment)	• Rigid registration to 3. • To compare catheter positions. • To compare dose distributions

Maenhout et al. Brachytherapy 2017

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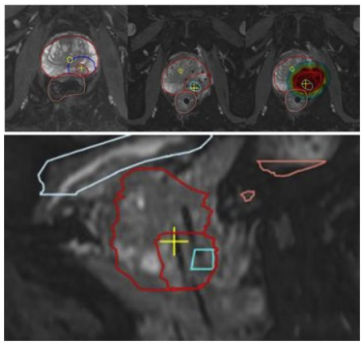
Utrecht MRI-Guided Workflow



Maenhout et al. Brachytherapy 2017

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Why not MRI-only?

Logistics

- Lack of real-time feedback during MRI needle positioning
- Difficult visualization of the needles
- Long scanning time

Planning

- Long planning times due to needles reconstruction
- Uncertainties in reconstruction can affect plan quality
- Use of fusions introduces registration uncertainties

Wish list

- Real-time, clear visibility during implantation
- Automatic needle path detection

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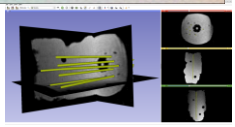
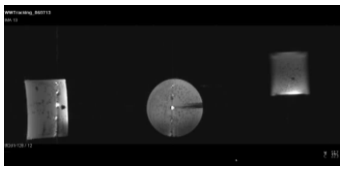
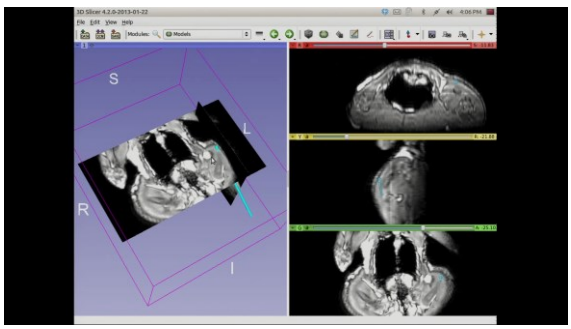
Active MR Tracking: Needle Identification



- Coils mounted on stylet
- Capture location along length of needle
- User identifies channels
- Controls MR scan plane through tip of needle.



Needle Guided MR Resampling of Initial Scan



Courtesy: Robert Cormack

Courtesy: Luc Beaulieu

EM-assisted US HDR brachytherapy

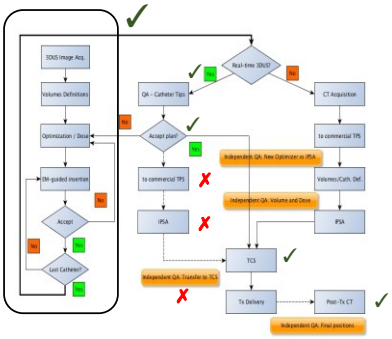
Guidance is always on – no needle searching

Catheter reconstruction
- On the fly

Streamline interface and workflow: < 1h procedure?

Workflow is same for whole gland and focal therapy

Tips position accuracy and comparison to CT



Beaulieu et al., Brachytherapy 2017

CONCLUSION

EM-tracking:

- QA: digitization and more if mounted on afterloader
- QA: software/hardware error detection system
- Digitzation/navigation presents a registration problem
- In pre-clinical phase for US-based brachytherapy
- Clinical use ongoing for breast brachytherapy

Active MRI tracking:

- Demonstrated clinical utility in assisting implantation
- Custom device requiring ad-hoc development

Acknowledgements

MSKCC:
Michael Zelefsky
Marisa Kollmeier
Sean Mc Bridge
Kaled Alektiar
Gil Cohen
Johnny Chiu
Karen Episcopia
Nitin Mathur
Laszlo Voros

Johns Hopkins
Akila Viswanathan

Brigham and Women's Hospital
Robert Cormack

Sunnybrook
Ananth Ravi; Aman Taggar