Advances and Innovations in Image-Guided Brachytherapy

Modern Interstitial GYN Brachytherapy

Antonio Damato, PhD
Brigham and Women's Hospital

Damato: August 2, 2016

Conflicts:

Travel grant from Elekta

Consulting agreement with Augmenix

Some non FDA-approved devices will be discussed

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Modern Interstitial GYN Brachytherapy

1. Use of MR

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1992

Int J Radiat Oncol Biol Phys. 1992;23(1):169-74.

Magnetic resonance imaging during intracavitary gynecologic brachytherapy.

Schoeppel SL[1], Ellis JH, LaVigne ML, Schea RA, Roberts JA.

Author information

[1]Department of Radiation Oncology, University of Michigan Medical Center, Ann Arbor 48109.

Abstract

The cases of three patients, two with Stage III-B and one with Stage II-B carcinoma of the cervix, are cited to illustrate specific advantages of magnetic resonance (MR) imaging over computed tomography (CT) during intracavitary gynecologic brachytherapy. CT and MR were performed during the first of two intracavitary implants. To obtain artifact-free images with the intracavitary implant in place, a CT- and MR-compatible Fletcher system applicator was used. Although CT failed to differentiate the cervical tumor clearly from surrounding tissues, the area of pathology could be identified on MR by comparing the T1-weighted (T1W) and T2-weighted (T2W) images. Cervical tumors typically exhibit low-signal intensity on T1W and high-signal intensity on T2W scans, whereas paracervical soft tissues demonstrate high intensity on both T1W and T2W images. This contrast permits the size, location, and paracervical involvement of the tumor to be defined by MR. Multiplanar MR images obtained during the patients' intracavitary brachytherapy help demonstrate the actual anatomic relationship between the tumor and the applicator. Isodose distributions displayed on these images show that, in two cases, the tumor margin extended beyond the prescribed isodose line. Thus, MR may prove to be a clinically useful reference during intracavitary brachytherapy for ascertaining radiation dose to actual tumor volume.

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Late 90s

Brigham and Women's Hospital, Boston, MA

- Open 0.5T MRI
- GYN protocol starting in 2004

Medical University of Vienna

- Open 0.2T MRI
- Systematic GYN use in 2001

Clinical imaging

Clinical impact of MRI assisted dose volume adaptation and dose escalation in brachytherapy of locally advanced cervix cancer

Richard Pötter, Johannes Dimopoulos, Petra Georg, Stefan Lang, Claudia Waldhäusl, Natascha Wachter-Gerstner, Hajo Weitmann, Alexander Reinthaller, Tomas Hendrik Knocke, Stefan Wachter, Christian Kirisits

Abstract

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2000-2010

GEC-ESTRO

- Working group established in 2000
- Reports on many aspects of MRI–guided cervix brachytherapy starting in 2005

"MRI has been clearly demonstrated to be superior to any other imaging procedure in cervix cancer allowing an accurate definition of the tumor"

Haie-Meder et al., *Radiother Oncol* 2005

Clinical and Physics Reports

Vienna, ~2005
- 0.2T open geometry
- T2 FSE multi-planar, 5mm

Brigham and Women's Hospital, ~2007
- 0.5T open geometry
- Real time needle insertion (4s increments)
- T2 multi-planar; T1

Aahrus, ~2008
- 1.5T
- T2 TSE multi-planar, 5mm (for contouring and planning)
- T1 TSE, 3mm (to help with planning)
- Oil / CuSO4 used in dummies to enhance applicator visibility

Insitut Gustave Roussy, ~2009
- T2 FSE, 3mm

Utrecht, ~2009
- 1.5T
- T2 TSE 4.5mm (for contouring)
- T1 SPIR, bSSFP, 1.5mm (for reconstruction)

Clinical and Physics Reports

Brigham and Women's Hospital, ~2012
- 3T
- 3D T2 (FSE, GRE, bSSFP) 1.6mm (for contouring and planning)

Washington University, ~2014
- 1.5T
- T2 + DWI, 5mm (ADC map for GTV contouring)

UPMC, ~2014
- 1.5T
- 3D T2, 2mm

Wisconsin, ~2014
- 3T
- 3D T2, 1mm

Institution (Years reported)	# Patients	Mode of treatment	Stage	Imaging During BT	Median Follow up (years)	Local control (%)	Disease specific Survival (%)	Overall Survival (%)	Late Grade 3-4 Toxicity %(#)
Vienna (1993-1997)	189	EB/HDR	IA-IVB	CT	2.8	78^	68^	58^	(3GU), (4 GI), (31 V)^
Vienna (1998-2003)	145	EB+/-Ch¥-HDR	IA-IVA	MR	4.3	85^	68^	58^	(3GU), (4GI), (5V)^
Vienna (2001-2008)	156	EB+/-Ch≠-HDR	IA-IVA	MR	3.5	95^	74^	68^	(3GU), (5GI), (2V) ^
IGR (2000-2004)	39	Pre-op LDR	IB1-IIB	MR	4.4	91±	86±	94±	0
IGR (2000-2004)	84	ChRT/LDR	IB2-IVB	MR	4.4	89±	52±	57±	(3GU; 1GI) ±
IGR (2004-2006)	45	ChRT/PDR	IB-IVA	MR	2.2	100+	73+	78+	(1 Fi) +

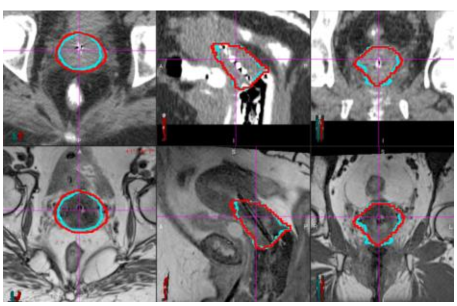
Courtesy of Akila Viswanathan, MD, MPH

Why post-EBRT MR?

- Tumor response varies by patient
  - **TUMOR SIZE**: good vs. bad EBRT responders[1]
  - **TUMOR SHAPE**: asymmetric tumors
- Using CT instead:
  - **HR-CTV**: not visible in CT, visible in MR
  - **OAR**: better visibility in MR, but MR ≈ CT
- MRI-guided insertions:
  - **NEEDLE GUIDANCE**: tumor visualization needed
  - **NEEDLE VISIBILITY**: need to see also the needles!

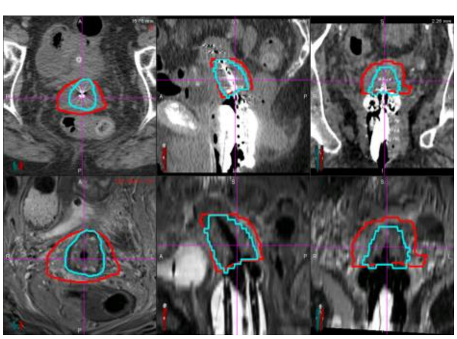
[1] Viswanathan et al, *IJROBP.* 2014

Small changes from EBRT



Viswanathan et al, *IJROBP.* 2014

Large changes from EBRT



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Downsides of MR

- Logistics
  - **AVAILABILITY**: dedicated MRs are rare commodities
  - **ACCESS**: bore geometry; stirrups; coils
- Safety:
  - **PULL**: ferromagnetic materials
  - **HEATING**: heating of metallic elements
- Other imaging modalities:
  - **ULTRASOUND**: useful for tandem insertion
  - **CT**: may be used to help with planning

Planning on MR

Applicator / Needles reconstruction

- In literature, details often omitted
- Model based applicator reconstruction on T2 images
- Needles?
  - Dummy markers? (Copper Sulfate?)
  - Some institutions use a mix of T1 and parasagittal T2
  - 3D images also used
  - (Many?) institutions use CT, with or without fusion

Pitfalls

- Fusion uncertainties can be hard to quantify
- Anatomy / shifts between MR and CT

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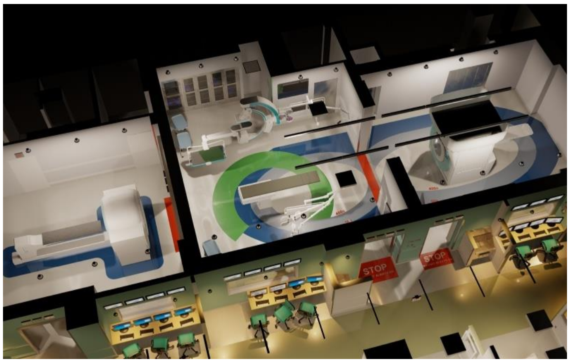
AMIGO



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Preliminary implantation under ultrasound guidance in OR room

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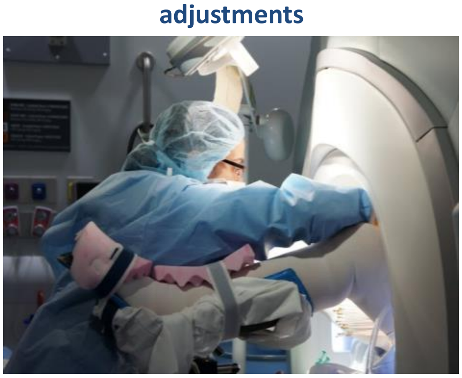
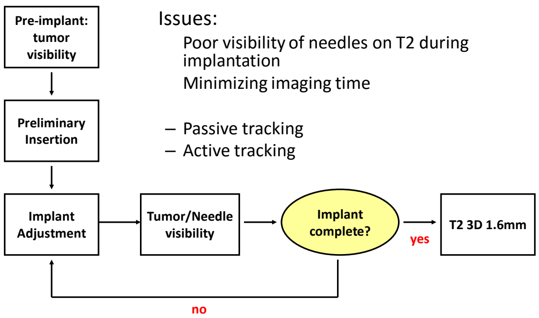
MR guided needle insertion and adjustments



MR Guided Interstitial Implantation Workflow

Issues:
- Poor visibility of needles on T2 during implantation
- Minimizing imaging time
  - – Passive tracking
  - – Active tracking



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Modern Interstitial GYN Brachytherapy

2. Use of needles

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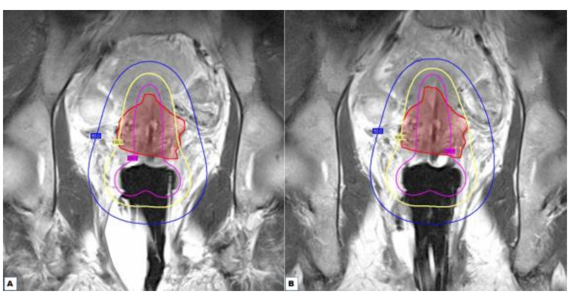
Courtesy of Akila Viswanathan, MD, MPH

Image-based GYN Brachytherapy

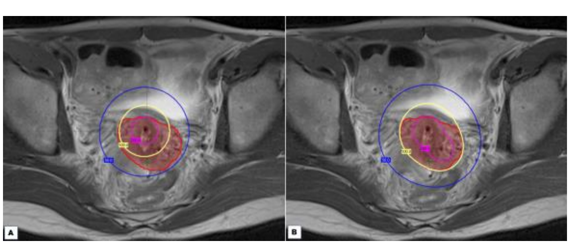
- Insertion:
  - **SELECTION**: brachytherapy technique
  - **GUIDANCE**: applicator positioning, needle insertion
- Dose Evaluation:
  - **ISODOSES**: visualize dose on patient anatomy
  - **METRICS**: D2cc, D90, …, summarize plan quality
- Patient-specific Planning:
  - **OPTIMIZATION**: depart from standard plan to adjust to patient-specific considerations
  - **ITERATIVE EVALUATION**: isodoses and metrics real-time evaluation during optimization

Standard vs Customized



Damato, Viswanathan, *MRI Clinics of North America, in press*

Standard vs Customized



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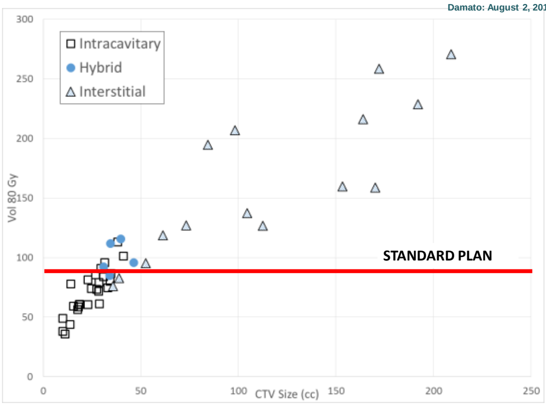

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Metrics

Table 2. Dose–volume histogram parameters related to primary tumor target

	Aarhus		Vienna	
Parameter	Standard	Optimized	IC; Kirisits *et al.* (11)	IC/IS; Kirisits *et al.* (12)
Patients (*n*)	—	21	22	22
BT fractions (*n*)	—	56	76	44
Prescribed dose ($Gy_{\alpha\beta10}$)	83 ± 1	83 ± 1	85 ± 4	85 ± 2
TRAK	1.6 ± 0.3	1.5 ± 0.4	1.7 ± 0.3	1.9 ± 0.2
V_{PD} (cm^3)	86 ± 4	80 ± 17	85 ± 19	101 ± 18
V_{2PD} (cm^3)	30 ± 1	29 ± 9	25 ± 8	33 ± 7
Point A, all patients ($Gy_{\alpha\beta10}$)				
Average left and right	84 ± 1	82 ± 6	—	—
Difference	0.2 ± 0.9	4.5 ± 8	—	—
Point A, IC patients only* ($Gy_{\alpha\beta10}$)				
Average left and right	84 ± 1	81 ± 5	82 ± 9	—
Difference	0.2 ± 0.8	2.8 ± 2	—	—
HR-CTV				
Volume (cm^3)	—	34 ± 12	34 ± 17	44 ± 27
D_{100} ($Gy_{\alpha\beta10}$)	73 ± 7	76 ± 5	66 ± 7	70 ± 6
D_{90} ($Gy_{\alpha\beta10}$)	89 ± 10	91 ± 8	87 ± 10	96 ± 12
V_{100} (%)	92 ± 9	96 ± 7	89 ± 8	93 ± 9

Lindegaard et al., *Radiother Oncol. 2008*

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Metrics

Table 3. Dose–volume histogram parameters related to organs at risk

	Aarhus		Vienna	
Parameter	Standard	Optimized	IC; Kirisits *et al.* (11)	IC/IS; Kirisits *et al.* (12)
Bladder				
Sparing factor	0.72 ± 0.32	0.61 ± 0.20	—	—
ICRU point ($Gy_{\alpha\beta3}$)	75 ± 31	67 ± 8	75 ± 16	73 ± 19
$D_{0.1}$ ($Gy_{\alpha\beta3}$)	99 ± 45	86 ± 12	121 ± 25	113 ± 30
D_1 ($Gy_{\alpha\beta3}$)	83 ± 22	77 ± 8	92 ± 11	90 ± 16
D_2 ($Gy_{\alpha\beta3}$)	78 ± 16	73 ± 6	83 ± 9	83 ± 14
Dose rate D_2 ($Gy_{\alpha\beta3}$)	0.93 ± 0.56	0.69 ± 0.20	HDR	HDR
Rectum				
Sparing factor	0.50 ± 0.25	0.47 ± 0.22	—	—
ICRU point ($Gy_{\alpha\beta3}$)	70 ± 5	71 ± 7	69 ± 13	71 ± 13
Rectal diode ($Gy_{\alpha\beta3}$)	63 ± 6	63 ± 5	60 ± 8	63 ± 9
$D_{0.1}$ ($Gy_{\alpha\beta3}$)	74 ± 10	74 ± 9	77 ± 10	77 ± 9
D_1 ($Gy_{\alpha\beta3}$)	69 ± 7	69 ± 6	66 ± 7	69 ± 6
D_2 ($Gy_{\alpha\beta3}$)	67 ± 6	67 ± 6	64 ± 6	66 ± 6
Dose rate D_2 ($Gy_{\alpha\beta3}$)	0.52 ± 0.21	0.48 ± 0.18	HDR	HDR
Sigmoid				
Sparing factor	0.59 ± 0.20	0.51 ± 0.13	—	—
$D_{0.1}$ ($Gy_{\alpha\beta3}$)	82 ± 13	79 ± 10	79 ± 12	85 ± 14
D_1 ($Gy_{\alpha\beta3}$)	74 ± 10	72 ± 7	67 ± 8	71 ± 8
D_2 ($Gy_{\alpha\beta3}$)	72 ± 9	69 ± 6	63 ± 7	67 ± 7
Dose rate D_2 ($Gy_{\alpha\beta3}$)	0.72 ± 0.32	0.58 ± 0.21	HDR	HDR

Lindegaard et al., *Radiother Oncol. 2008*

Vaginal Indication for Needles

- Main criteria:
  - "Residual vaginal lesions > 0.5 cm thick are potential candidates for interstitial brachytherapy"[†]
- Other considerations:
  - Available expertise
  - Medical considerations (comorbidities)
- Available applicators:
  - Vaginal Cylinder: simple; limited OAR sparing
  - Shielded Cylinder: improved OAR sparing; difficult quantitative dosimetry
  - Multi-channel applicators: effectiveness varies with tumor location

[†] Beriwal et al, Brachytherapy 11 (2012) 68-75

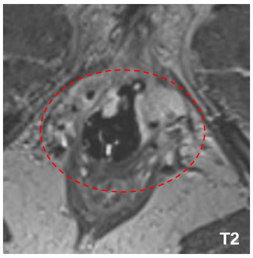
Case Planning

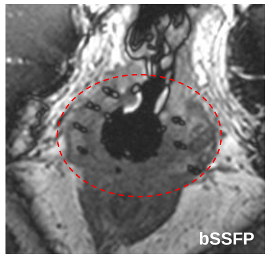
- Planning:
  - Target contoured on MR; OAR on CT/MR
  - CT/MR fusion based on implant
  - MR planning followed by CT verification
- Metrics are evaluated in EQD2:
  - Rectum < 75 Gy_{EQD2} : 73 Gy_{EQD2} for this case
  - Bladder < 90-100 Gy_{EQD2} : 95 Gy_{EQD2} for this case
  - D90 = 70 Gy_{EQD2}, with central areas receiving > 100Gy_{EQD2}
- Once a limit is reached, a clinical decision is made on best balance between coverage and OAR sparing

Modern Interstitial GYN Brachytherapy

3. Visualizing needles

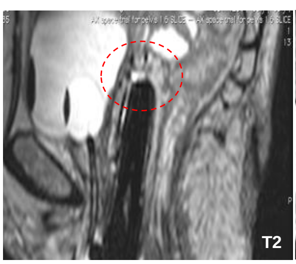
Passive needle identification

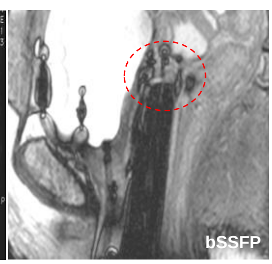




Kapur et al., *Magn Reson Imaging*. 2012

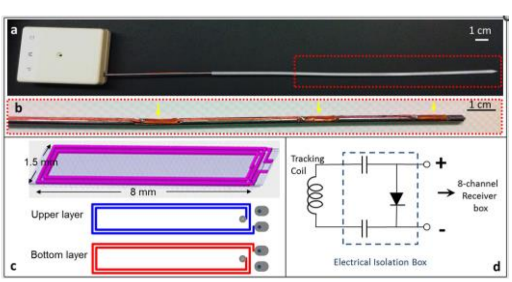
Passive needle identification





Kapur et al., *Magn Reson Imaging*. 2012

ACTIVE MR TRACKING

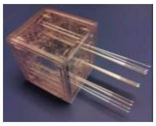


Wang et al., Magn Reson Med. 2015 May; 73(5):1803-11

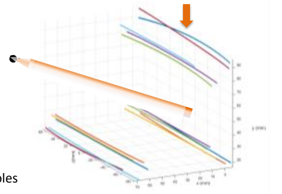
Damato: August 2, 2016 (Courtesy: W. Wang)

Catheter Trajectory Reconstruction by MR Tracking

Phantom Study

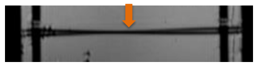


Fifteen needles: 9 parallel + 3 pairs crossed
Through two templates with 5 mm grid of holes



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

3D distance: 1.1 ± 0.9 mm



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

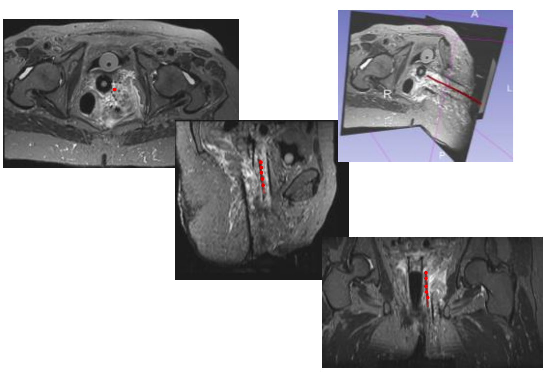
Two bent needles

Two crossed needles

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

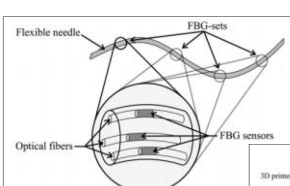
Damato: August 2, 2016 (Courtesy: W. Wang)

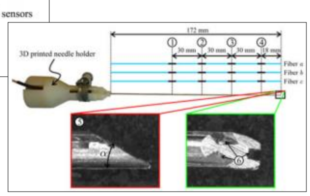
Catheter Trajectory Reconstruction by MR Tracking



Damato: August 2, 2016
(Thanks to Luc Beaulieu)

FIBER BRAGG GRATING





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

Modern Interstitial GYN Brachytherapy

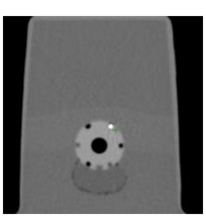
4. Future Work

When MR is not always available

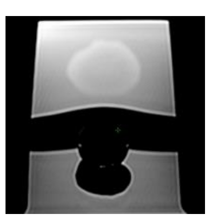
- MR common in hospitals, not in RadOnc:
  - **OFF-LINE MR**: implants in OR, then MRI imaging
  - **MR GUIDANCE**: need an MR-equipped OR
- MR imaging always desirable, in particular:
  - **FIRST FRACTION**: depending on EBRT/BT timing
  - **SELECTED PATIENTS**: large pre-EBRT tumors
- Future work:
  - **VIRTUAL MR**: electromagnetic guidance
  - **TRUS**: ultrasound as an alternative to MR

VIRTUAL MR GUIDANCE

Phantom Pre-Insertion: Modified Prostate Training Phantom

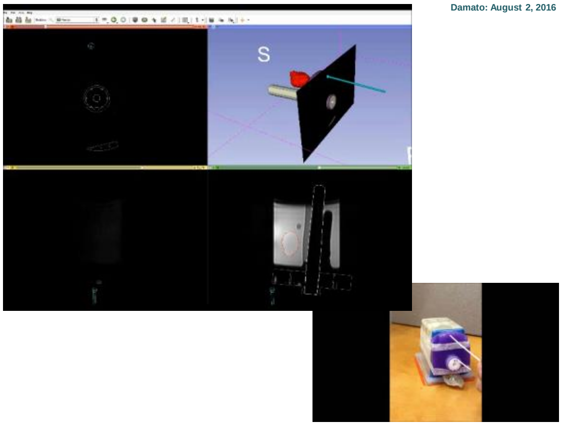


CT: implant identification

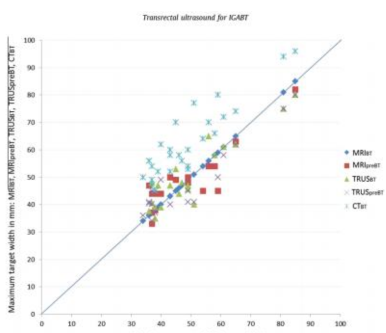


MR: tumor identification

Mehrtash et al.; *Proc Soc Photo Opt Instrum Eng.* 2014

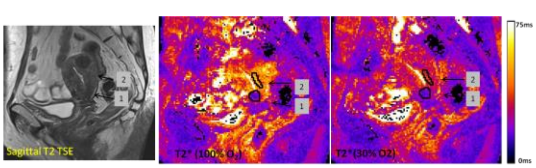


TRUS



Schmid et al.; *Radiother Oncol.* 2016

Personalized Planning



Sub-volume Implant

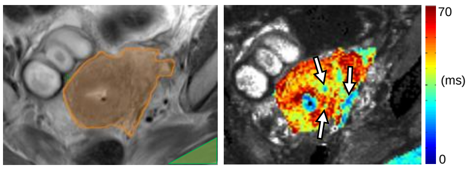
- Non-destructive sub-volume analysis
- Does not constrain follow up

Controlled placement of high dose regions

- Exploiting brachytherapy characteristics
- Dose-escalate radio-resistant regions

Damato: August 2, 2016 (Courtesy: P. Ciris)

Results



Residual tumor & muscle contours on T_2-TSE

T_2* map & color overlay within tumor and muscle contours

Damato: August 2, 2016

Conclusion

Major advance: visualization of the tumor

- Many technical aspects to MR
- QA / QC / workflow considerations
- Increased education of physicists (AAPM/ABS)

Technical solutions to technical challenges

- Tracking to resolve needle identification issues
- Tracking for situations in which MR-guidance not available

Possible future use of MRI

- For dose painting
- For focal brachytherapy