Advances and Innovations in Image-Guided Brachytherapy

Modern Interstitial GYN Brachytherapy

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Conflicts:

Travel grant from Elekta
Consulting agreement with Augmenix
Some non FDA-approved devices will be discussed

Modern Interstitial GYN Brachytherapy

1. Use of MR
1992

Magnetic resonance imaging during intracavitary gynecologic brachytherapy,
U. Schena T. Tielli S. Calancie E. Schena F. Soffietti

Abstract
The authors of the three patients, two with stage IIB and one with stage IIIC carcinoma of the cervix, are used to illustrate specific advantages of the use of pelvic magnetic resonance (MR) imaging over computed tomography (CT) during intracavitary gynecologic brachytherapy. CT and MR scans performed during the first of two intracavitarybrachytherapy. To obtain artifact-free images with the intracavitary insert in place, a 1.5-T and high-resolution Ektacyrter system was used. Although T1-weighted (T1W) and T2-weighted (T2W) images, cervical tumors typically exhibit low-signal intensity on T1W and high-signal intensity on T2W. In contrast, surrounding normal tissues demonstrated high intensity of the both T1W and T2W images. This contrast permits the size, location, and peripheral involvement of the tumor to be defined by MR. Multiphase (MR) images obtained during the patients' intracavitary brachytherapy may demonstrate the actual anatomic relationship between the tumor and the surrounding normal tissue. High-signal intensity of the MR may prove to be a clinically useful reference during intracavitary brachytherapy for accelerating radiation dose to actual tumor volume.

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

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

Aarhus, ~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 open geometry
- Real time needle insertion (4s increments)
- T2 multi-planar; T1 SPIR, bSSFP, 1.5mm (for reconstruction)

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

<table>
<thead>
<tr>
<th>Institution/Years reported</th>
<th>Patients</th>
<th>Mode of treatment</th>
<th>Stage</th>
<th>Imaging During BT</th>
<th>Median Follow up (years)</th>
<th>Local control (%)</th>
<th>Disease specific Survival (%)</th>
<th>Overall Survival (%)</th>
<th>Late Grade 3-4 Toxicity (#)</th>
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<tbody>
<tr>
<td>Vienna (1993-1997)</td>
<td>189</td>
<td>EB/EBD</td>
<td>I-A</td>
<td>CT</td>
<td>2.8</td>
<td>70*</td>
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<td>78*</td>
<td>(3GU), (4GI), (3V)</td>
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<td>I-A</td>
<td>EB+/-</td>
<td>4.4</td>
<td>75*</td>
<td>68*</td>
<td>(3GU), 1GI</td>
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<td>IGR (2004-2006)</td>
<td>48</td>
<td>CART/DIR</td>
<td>I-A</td>
<td>EB+/-</td>
<td>2.2</td>
<td>73*</td>
<td>78*</td>
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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

![Small changes from EBRT](Viswanathan et al, IJROBP. 2014)

Large changes from EBRT

![Large changes from EBRT](Viswanathan et al, IJROBP. 2014)
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Viswanathan et al, IROBP. 2014
```

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
Preliminary implantation under ultrasound guidance in OR room

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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<td>145</td>
<td>Elec/1D/Cx, HDR</td>
<td>IB1-IVB</td>
<td>MR</td>
<td>4.3</td>
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<td>Pre-op LDR</td>
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<td>MR</td>
<td>4.4</td>
<td>51%*</td>
<td>86*</td>
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</tr>
<tr>
<td>IGRT (2000-2004)</td>
<td>54</td>
<td>CART/3D DR</td>
<td>III-IVB</td>
<td>MR</td>
<td>4.4</td>
<td>52%*</td>
<td>77*</td>
<td>(3GU), (1 GI), (1 RV)</td>
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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

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**Standard vs Customized**


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**Standard vs Customized**

Metrics

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

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Authors</th>
<th>Standard</th>
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<th>IC: Kiran et al. (11)</th>
<th>IC: IR: Kiran et al. (12)</th>
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<td>D90% (%)</td>
<td>89 ± 3%</td>
<td>92 ± 3%</td>
<td>90 ± 3%</td>
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<td>90 ± 3%</td>
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<tr>
<td>D2% (%)</td>
<td>2%</td>
<td>4%</td>
<td>2%</td>
<td>4%</td>
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<tr>
<td>V100% (cc)</td>
<td>75 ± 3%</td>
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<tr>
<td>V107% (cc)</td>
<td>10 ± 3%</td>
<td>10 ± 3%</td>
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Lindegaard et al., Radiother Oncol. 2008

Metrics

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

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<th>Parameter</th>
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<tr>
<td>D90% (%)</td>
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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


Passive needle identification


ACTIVE MR TRACKING

Phantom Study

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

A. MRI-image based needle digitization
B. Active Tracking during stylet pull-out
3D distance: 1.1 ± 0.9 mm

Catheter Trajectory Reconstruction by MR Tracking


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

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
Results

Residual tumor & muscle contours on T2-TSE

T2* map & color overlay within tumor and muscle contours

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