3D Dose Distribution Uncertainties when Combining EBRT with Brachytherapy in Cervical cancer.

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Disclosure

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UNCERTAINTIES RELATED TO MRI DISTORSIONS
MR-guided Brachytherapy for cervical cancer

- MRI increasingly used for BT planning
- Local magnetic field inhomogeneity
  - geometrical deformations
- Applicator displacement impacts dose calculation
• Distortions are considered acceptable at 1.0 T and 1.5T → brachytherapy planning is feasible

• 3T has potential for higher SNR and functional imaging

Tanderup et al. 2008
Image Distortion due to $B_0$ Inhomogeneity

Local variation in the main magnetic field $\Delta B_0$ → spins resonate with different frequency than intended

- Signal from spin will be reconstructed at a different location

- Distortion is most pronounced in the read out direction
Image Distortion due to $B_0$ Inhomogeneity

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- Signal from spin will be reconstructed at a different location

- Distortion is most pronounced in the read out direction
Experiments

- Verify method with narrow bandwidth scans in phantom
- **Quantify displacement on clinical T2W scans for phantom**

Rigid matching method

B₀ map
Method: Rigid Registration

Opposing read-out direction

- Distortion changes direction
- Overlay images and invert greyscale

Cross-section of Applicator in phantom → Overlay of opposing readout direction images → Shift in A-P direction to compensate displacement
**Method: $B_0$ Map**

$B_0$ field map

- $\Delta B_0$ characterizes magnetic field inhomogeneity

- Displacement map can be calculated from $B_0$ field map
  - Using the scan sequence parameters (bandwidth, pixel size)

\[
\text{Displacement (mm)} = \frac{\Delta B_0}{\text{bandwidth}} \cdot \text{pixel size}
\]
Results of Displacements according to Bandwidth

BW: 18.1 Hz
33.3 Hz
63.3 Hz

Van Heerden et al. Brachytherapy 2016

Narrow bandwidth scans: $B_0$ map shifts agree with rigid match shifts
Results of Displacement Measured at Clinically used Bandwidth

Anatomical scan (Phantom)  
BW: 311 Hz

Small compared to resolution of 0.8 mm

- B₀ field map
- Rigid registration

Van Heerden et al. Brachytherapy 2016
Quantification of Displacements and their Dosimetric Impact

van Heerden et al. Int J Radiat Oncol Biol Phys 2017
Quantification of Displacements and their Dosimetric Impact

Limited Dosimetric impact caused by distortions

van Heerden et al. Int J Radiat Oncol Biol Phys 2017
• For the Utrecht Interstitial CT/MR brachytherapy applicator and used MR sequence, applicator distortion from $B_0$ inhomogeneity $< \text{pixel size}$

• Dosimetric effects caused by the geometric distortions can be neglected
UNCERTAINTIES RELATED TO DOSE ACCUMULATION
3D Dose Addition for Cervical cancer

What we do now:

External beam radiotherapy

Brachytherapy

Planned dose OR $D_{1cc}$, $D_{2cc}$ etc. (in equivalent dose)

$D_{1cc}$, $D_{2cc}$ etc. (in equivalent dose)
Direct DVH Parameter Addition

- Dose is possibly non-uniform in OAR
  - IMRT & VMAT → conformal dose distributions

- Take deformation of anatomy into account → Deformable image registration
Method: Direct Parameter Addition

Uniform Dose

EBRT

Uniform
EBRT dose

46 Gy

BT

BT $D_{2\text{cm}3}$

Cumulative $D_{2\text{cm}3}$

Overlapping High Dose

EBRT

EBRT $D_{2\text{cm}3}$

Cumulative $D_{2\text{cm}3}$

BT

BT $D_{2\text{cm}3}$

Cumulative $D_{2\text{cm}3}$
Method: DIR

3D dose addition with DIR

EBRT + BT

Cumulative $D_{2cm^3}$
Study design

- 12 patients
- EBRT: 23 x 2 Gy
- Brachy boost: 24 Gy\text{EQD}_2

- EBRT: planning CT + bladder & rectum contours
- Brachytherapy: planning MRI + bladder & rectum contours
Study set-up

- **Deformable image registration**
  - Separate bladder and rectum match
  - Only use contour information
  - Convert to 3D meshes
  - Feature-based tool (Elekta Brachytherapy)\(^1,^2\)

- EBRT dose is **deformed** to BT frame of reference

\(^1\)Vásquez Osorio et al. Med Physics 2009
\(^2\)Bondar et al. Medical Physics 2010
Comparison Between Methods

3D dose addition with DIR
- EBRT
- BT

Direct addition methods
- Uniform Dose
- Overlapping High Dose volumes

Bladder and rectum $D_{2cm3}$ and $D_{1cm3}$
Results: Bladder

• DIR - Uniform Dose
  - $\Delta D_{2\text{cm}^3}$: 0.1 (-1.8 – 1.5)
  - $\Delta D_{1\text{cm}^3}$: 0.2 (-0.8 – 1.1)

• DIR - Overlapping High Dose
  - $\Delta D_{2\text{cm}^3}$: -1.8 (-3.2 – -1.0)
  - $\Delta D_{1\text{cm}^3}$: -2.0 (-3.3 – -0.9)

Van Heerden et al. Radiother Oncol 2017
Results: Rectum

- **DIR - Uniform Dose**
  - \( \Delta D_{2cm^3} \): -0.4 (-1.7 – 1.1)
  - \( \Delta D_{1cm^3} \): -0.3 (-1.6 – 0.9)

- **DIR - Overlapping High Dose**
  - \( \Delta D_{2cm^3} \): -1.1 (-0.6 – -2.2)
  - \( \Delta D_{1cm^3} \): -1.3 (-0.6 – -2.3)

Van Heerden et al. Radiother Oncol 2017
• For evaluation of cumulative $D_{2\text{cm}^3}$ and $D_{1\text{cm}^3}$ from EBRT and BT in bladder and rectum.

– No added value for DIR: Small differences ($<3.2\text{Gy}_{\text{EQD2}}$) were found with direct addition methods.

– The EBRT planned dose distribution can be considered uniform.
Planned EBRT dose can be considered homogeneous in OARs

Also true for delivered dose?
Planned vs. Delivered Dose

- Delivered dose may be different:
  - Interfraction motion
    - Variation in patient position
    - Variation in organ filling
  - Multiple plans were used
    - Replanning
    - Plan-of-the day approach

- → non-uniform delivered EBRT dose to BT high dose volumes.
Patients and Method

- 10 patients:
- External beam radiation treatment
  - 8: $46 \text{ Gy}_{\text{EQD}2}$ in 23 fractions
  - 2: $46.2 \text{ Gy}_{\text{EQD}2}$ in 28 fractions
  - 1-3 plans (plan of the day approach)
- Brachytherapy
  - MRI-guided Pulsed dose rate BT boost of $28\text{ Gy}_{\text{EQD}2}$
Plan-of-the-day

Variable dose on OARs
Methods: Delineation & DIR

- Deform planning CT to CBCT and calculate dose using plan of the day
Dose Accumulation of Delivered EBRT Dose

CBCT fraction 1 + CBCT fraction 2,3,4 etc.
Dose Accumulation of Delivered EBRT Dose

Delivered EBRT dose

CBCT fraction 1, CBCT fraction 2, 3, 4 etc.
EBRT + BT Dose Accumulation

- **Deformable image registration**
  - Bladder and rectum match
  - Using structure-based DIR method available in Velocity

- Accumulated, delivered EBRT dose is **deformed** to BT frame of reference
Deformable Image Registration (DIR): Dose Accumulation

Delivered EBRT

BT
Deformable Image Registration (DIR): Dose Accumulation
Deformable Image Registration (DIR): Dose accumulation

Delivered EBRT  BT
Bladder

### Table: Bladder doses

<table>
<thead>
<tr>
<th>Method</th>
<th>DIR Mean (Range)</th>
<th>Uniform dose Mean (Range)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$D_{2\text{cm}^3}(\text{Gy}_{\text{EQD2}})$</td>
<td>75.6(57.4;106.9)</td>
<td>74.5(56.6;103.2)</td>
</tr>
<tr>
<td>$\Delta D_{2\text{cm}^3}(\text{Gy}_{\text{EQD2}})$</td>
<td>-</td>
<td>-1.1(-0.2;3.7)</td>
</tr>
</tbody>
</table>
Rectum

Rectum

<table>
<thead>
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<th>Method</th>
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</thead>
<tbody>
<tr>
<td>$D_{2cm} (Gy_{EQD2})$</td>
<td>63.2 (50.6; 74.7)</td>
<td>63.3 (49.7; 77.5)</td>
</tr>
<tr>
<td>$\Delta D_{2cm} (Gy_{EQD2})$</td>
<td>-</td>
<td>0.0 (-1.0; 2.8)</td>
</tr>
</tbody>
</table>
- Small differences in total EBRT +BT dose(<3.7Gy\textsubscript{EQD2}) were found with direct addition method.

- The EBRT delivered dose distribution can be considered uniform.
Conclusion

Geometric MR distortions have small effect on dosimetry

Planned and delivered EBRT dose can be considered homogeneous in OAR

There is limited value of using DIR methods for dose summation of EBRT to brachytherapy
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