Image guided adaptive brachytherapy (in cervix cancer) – Physics aspects

Christian Kirisits
Cervical Cancer FIGO IIIB

Sagittal view
Coronal view
Axial view

DIAGNOSIS

Cervical Cancer FIGO IIIB

ATGABT = Image Guided Adaptative Brachytherapy

25 Months Follow up

IGABT = Image Guided Adaptative Brachytherapy

High Risk CTV = HRCTV

GTV

IRCTV

Months Follow up
In-room imaging?
Visualization of the “real” source positions in relation to the outer dimensions and holes of the Vienna ring applicator.
Planned positions verified by QA
(autoradiography)
Applicator surface
Source path
Applicator + Source path
Registration of dose delivery device with anatomy
Treatment Planning directly on 3T MR

- Import vendor provided archived applicator into planning images
- Can use with 3D SPACE or T2 FSE

Courtesy B. Erickson, MCW
Treatment planning
Standard loading pattern
Shifting and skipping dwell positions
Standard loading pattern
Optimized loading pattern
Standard loading
Inverse optimization
Use with caution due to missing constraints for spatial dose distribution!
Dose Optimization

DVH parameters (D90, D98, \( D_{2cc} \), \( D_{0.1cc} \))

Spatial dose distribution (Hot and Cold spots)

Dwell time distribution to take into account
not contoured structures
parametrial tissue
vagina
nerves
vessels
ureter
Manual optimization
Manual plan
Inverse optimization
Application technique and patterns of tumor regression
Vienna I and Vienna II applicators

a) R34
b) R30
c) R26

holes for straight needles
holes for divergent needles
additional holes for r26

Berger et al.
COMMERCIAL PRODUCTS

Venezia: optimizing dose distribution with interstitial needles

Intracavitary brachytherapy

With parallel needles

With parallel and oblique needles
(The parallel needles are not on the same plane)

Based on
Preplanning without applicator in situ
3D printed applicators

preplan

Virtual design

3D print

Implant

Dose Distribution at Ovoids with shields

TG43 (no shields)  TG186 (shields modeled)

Output of OncentraBrachy 4.5 with ACE - courtesy of F. Mourtada
Review of clinical brachytherapy uncertainties: Analysis guidelines of GEC-ESTRO and the AAPM

Christian Kirisits, Mark J. Rivard, Dimos Baltas, Facundo Ballester, Marisol De Brabandere, Rob van der Laarse, Yury Niatsetski, Panagiotis Papagiannis, Taran Paulsen Hellebust, Jose Perez-Calatayud, Kari Tanderup, Jack L. M. Venselaar, Frank-André Siebert

Radiother Oncol 2014
## Example for HDR intracavitary Cervix brachytherapy – per fraction

<table>
<thead>
<tr>
<th>Category</th>
<th>Optimum level</th>
<th>Assumptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Source strength</td>
<td>2%</td>
<td>PSDL traceable calibrations</td>
</tr>
<tr>
<td>Treatment planning</td>
<td>3%</td>
<td>Reference data with the appropriate bin width is used</td>
</tr>
<tr>
<td>Medium dosimetric corrections</td>
<td>1%</td>
<td>Applicator without shielding and CTV inside pelvis (concerning for scatter)</td>
</tr>
<tr>
<td>Dose delivery including registration of applicator</td>
<td>4%</td>
<td>Accurate QA concept for commissioning &amp; constancy checks, especially for source positioning and applicator/source path geometry, appropriate imaging, applicator libraries</td>
</tr>
<tr>
<td>geometry to anatomy</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interfraction/Intrafraction changes</td>
<td>11%</td>
<td>For one treatment plan per applicator insertion but several subsequent fractions – check for major deviations in subsequent fractions</td>
</tr>
<tr>
<td>Total dosimetric uncertainty for one single fraction</td>
<td>12%</td>
<td></td>
</tr>
</tbody>
</table>
Example for HDR intracavitary Cervix brachytherapy – total dose 4 fractions

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<td>Dose delivery including registration of applicator geometry to anatomy</td>
<td>$\frac{1}{\sqrt{N}}$</td>
<td>Accurate QA concept for commissioning &amp; constancy checks, especially for source positioning and applicator/source path geometry, appropriate imaging applicator libraries</td>
</tr>
<tr>
<td>Interfraction/Intrafraction changes</td>
<td>$\frac{1}{\sqrt{N}}$</td>
<td>For one treatment plan per applicator insertion but several subsequent fractions –</td>
</tr>
<tr>
<td>Total dosimetric uncertainty for entire BT</td>
<td>7%</td>
<td></td>
</tr>
</tbody>
</table>
Expected interfraction variations for cervix BT

**Target**
should remain fixed relative to applicator

**Rectum:**
may slightly change in location and fill with gas

**Bladder:**
use of bladder filling protocols

**Sigmoid:**
change its location

Hellebust et al. R&O 60, 2002
Lang et al. R&O 107, 2013
Kirisits et al. R&O 2006
Nesvacil et al. R&O 107, 2013
Tanderup et al. R&O 107, 2013 (and references therein)

Radiother Oncol 107

ICRU 38 Ref. Points
Multicenter Center study of inter-/intrafraction variations for target and OARs in cervix BT

<table>
<thead>
<tr>
<th></th>
<th>$\Delta D_{2cm^3}$ between 2 acquisitions [%] (fixed plan, variable anatomy)</th>
<th>$\Delta D_{90}$ [%] (fixed plan, variable anatomy)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>bladder</td>
<td>rectum</td>
</tr>
<tr>
<td></td>
<td>Mean</td>
<td>median</td>
</tr>
<tr>
<td>total</td>
<td>2.7</td>
<td>1.5</td>
</tr>
<tr>
<td>Intraaplication</td>
<td>1.3</td>
<td>1.5</td>
</tr>
<tr>
<td>Interapplication</td>
<td>3.9</td>
<td>0.0</td>
</tr>
</tbody>
</table>

Random uncertainties (1SD) of physical dose per BT fraction can be
- ~ 10% for HR CTV D90 (contouring uncertainty (Petric, Hellebust R&O 2013))
- ~ 20% for bladder, rectum $D_{2cm^3}$
- ~ 30% for sigmoid $D_{2cm^3}$

No correlation with **time** between images was detected!

Nesvacil et al. 2013, Radiother Oncol 107
Increasing OAR dose constraints by reducing uncertainties

Clinician could consider relaxing the OAR dose constraint for this case!

Nesvacil et al. 2016
Image guidance for each fraction?

Combined MRI-/CT-guided BT for cervical cancer

1st application

MRI-based planning:
3D applicator reconstruction

Target delineation

OAR delineation

Dose planning and optimization

2nd application

CT-based planning:
3D applicator reconstruction

Automatic target transfer from MRI via applicator-based image registration

OAR delineation

Dose planning and optimization
1st application: MRI

Applicator, target (HR CTV), OAR (rectum, bladder, sigmoid)
Dose planning and optimization on target+organ contours
2nd application: CT

3D applicator reconstruction
2\textsuperscript{nd} application: CT

3D applicator reconstruction
Target transfer
2\textsuperscript{nd} application: CT

Automatic target transfer from MRI to CT with applicator as reference system

[CT scan images]
Ultrasound use in gynecologic brachytherapy: Time to focus the beam
Sylvia van Dyk, Michal Schneider, Srinivas Kondalsamy-Chennakesavan,
David Bernshaw, Kailash Narayan

Modern high-tech external beam
versus
Cheap and simple Brachytherapy

High-tech image-guided therapy versus low-tech, simple, cheap gynecologic brachytherapy.
Kirisits C, Schmid MP, Beriwal S, Pötter R.
Brachytherapy. 2015

IMRT, IGRT, and other high technology becomes standard in external beam radiotherapy: But is image-guided brachytherapy for cervical cancer too expensive?
Swamidas JV, Kirisits C.
J Med Phys. 2015
TRUS?

Transrectal ultrasonography...
...has „direct contact“ to the target volume
...has a reasonable soft tissue contrast
...allows dynamic real time imaging
...is already implemented in prostate cancer brachytherapy
...is a low cost imaging modality
...is widely available
Blinded retrospective analysis of consecutive patients at same time points n=19
Transrectal ultrasound for target definition in CT-based cervix cancer IGABT (no access to MRI @BT)


volumetric post-implant scan

pre-implant scan, TRUS guidance of implantation

TRUS target delineation

applicator tracking (ACMIT, Elekta)

main uncertainty: tracking

TRUS-CT registration via applicator
Depiction of Titanium needles on TRUS images

Comparison of target structures delineated on TRUS, CT and MRI – all targets transferred to CT by applicator-based registration, OAR delineation on CT

<table>
<thead>
<tr>
<th></th>
<th>CTV_{HR}^{CT}</th>
<th>CTV_{HR}^{US}</th>
<th>CTV_{HR}^{MRI}</th>
</tr>
</thead>
<tbody>
<tr>
<td>volume (cm³)</td>
<td>59</td>
<td>30</td>
<td>30.9</td>
</tr>
<tr>
<td>width (mm)</td>
<td>71</td>
<td>53</td>
<td>49</td>
</tr>
<tr>
<td>thickness (mm)</td>
<td>52</td>
<td>34</td>
<td>33</td>
</tr>
<tr>
<td>height (mm)</td>
<td>37</td>
<td>31</td>
<td>35</td>
</tr>
</tbody>
</table>

Table 9.1. A summary of clinical brachytherapy in vivo dosimetry studies.

<table>
<thead>
<tr>
<th>Dosimeter</th>
<th>Study</th>
<th>Site</th>
<th>Action Level / Comment</th>
<th>Uncertainty (1 σ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TLD</td>
<td>Brezovich et al (Brezovich et al 2000)</td>
<td>Prostate, Urethra, rectal dose,</td>
<td>Action level: 20% generally,</td>
<td>8-10%;</td>
</tr>
<tr>
<td></td>
<td>Das et al (Das et al 2007)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Toye W et al (Toye et al 2008)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Raffi et al (Raffi et al 2010)</td>
<td>skin (breast)</td>
<td></td>
<td>&lt;3% (TLD uncertainty budget)</td>
</tr>
<tr>
<td>MOSFET</td>
<td>Cygler et al (Cygler et al 2006)</td>
<td>Urethra (prostate seed implants)</td>
<td>Action level: 16%</td>
<td>8%</td>
</tr>
<tr>
<td></td>
<td>Bloemen-van Gurp et al (Bloemen-van Gurp et al 2009a)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alanine / ESR</td>
<td>Schultka et al (Schultka et al 2006)</td>
<td>GYN ((^{137})Cs)</td>
<td>Detector volume too large; Difference with planning 10+%</td>
<td>None provided</td>
</tr>
<tr>
<td></td>
<td>Anton et al (Anton et al 2009)</td>
<td>Urethra (prostate HDR)</td>
<td></td>
<td>5% (excl. source strength uncertainty)</td>
</tr>
<tr>
<td>Diodes</td>
<td>Alecu and Alecu (Alecu and Alecu 1999)</td>
<td>Cervix</td>
<td>Agreement with TPS within 15%</td>
<td>None provided</td>
</tr>
<tr>
<td></td>
<td>Waldhäusl C et al (Waldhäusl et al 2005)</td>
<td>Cervix</td>
<td>Action level: 10% (36/55 cases needs further investigation)</td>
<td>7%</td>
</tr>
<tr>
<td></td>
<td>Seymour et al (Seymour et al 2011)</td>
<td>Rectum (Prostate HDR)</td>
<td>95% measurements within 20%</td>
<td>9.8% (meas. only)</td>
</tr>
<tr>
<td>Glass Dosimeters</td>
<td>Takayuki et al (Nose et al 2008)</td>
<td>Prostate</td>
<td>Deviations of more than 20% seen.</td>
<td>None provided</td>
</tr>
<tr>
<td>-------------------</td>
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</tr>
<tr>
<td></td>
<td>Hsu et al (Hsu et al 2008)</td>
<td>GYN</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Takayuki et al (Nose et al 2008)</td>
<td></td>
<td></td>
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</tr>
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<td></td>
<td>Takayuki et al (Nose et al 2005)</td>
<td>H&amp;N</td>
<td></td>
<td></td>
</tr>
<tr>
<td>OSLD &quot;NanoDot&quot;</td>
<td>Sharma and Jursinic (Sharma and Jursinic 2013)</td>
<td>GYN, Breast</td>
<td>-4.4% to 6.5% difference to AcurosBV</td>
<td>None provided</td>
</tr>
<tr>
<td>Real-time OSL</td>
<td>Andersen et al (Andersen et al 2009)</td>
<td>Cervix (PDR)</td>
<td>Errors detection are distance dependent; Time-resolved measurements are better</td>
<td>5%</td>
</tr>
<tr>
<td>Plastic Scintillation</td>
<td>Suchowerska et al (Suchowerska et al 2011)</td>
<td>Urethra (prostate HDR)</td>
<td>Maximum deviation without imaging 67%; maximum deviation with imaging 9%</td>
<td>None provided</td>
</tr>
<tr>
<td>Dosimeters</td>
<td>MOSkin Carrara et al (Carrara et al 2016)</td>
<td>Rectum (Prostate HDR) Nasopharynx</td>
<td>Action level: 20%</td>
<td>2.5% (MOSkin uncertainty budget)</td>
</tr>
</tbody>
</table>
Dose delivery with in-vivo dosimetry verification

Courtesy of K. Tanderup
TIME-RESOLVED IVD!


Only time-resolved

Slide by L. Beaulieu, AAPM summer school 2017
Conclusion

• Infrastructure for imaging (equipment and staff)
• Reproducible and standardized concept for target and OAR delineation
• Applicator reconstruction
• Optimization (protocol including constraints for dose/volumes and dwell times)
• Dose and volume parameters for planning aim, prescription and reported (delivered) dose
• Lowering uncertainties with new technology