Anatomy-based Inverse Planning for Brachytherapy

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This work is supported in part by NUCLETRON
HDR Brachytherapy

- Define Target
- Localize catheters

- Dose Plan

- Tx

Cone Beam CT

Class solutions

Advanced 3D Planning
IMRT

- Define Target
- Localize catheters
- CT / MR
- Fluo + US
- Cone Beam CT
- Anatomy-based
- Inverse planning (IPSA)
- Class solutions

+ Dose Plan

+ Tx

QuickTime™ and a TIFF (Uncompressed) decompressor are needed to see this picture.
IMBT

Define Target
Localize catheters

CT / MR
Fluo + US
Cone Beam CT

Dose Plan
Anatomy-based
Inverse planning (IPSA)

Tx
Class solutions
Image-based Inverse Planning HDR

- Introduction to IPSA
- Performance
- Clinical examples
Anatomy Conformal Dose Optimization

description of the Dose Constraints
Inverse Planning

optimization engine
Simulated Annealing

IPSA
Physician's prescription = • Target contours
• Organ at risk contours
• Dose constraints on each target and organs at risk

**Target** (Prostate)
1 - Dose constraints

Physician's prescription = • Target contours
• Organ at risk contours
• Dose constraints on each target and organs at risk

Acceptable dose range

Penalized dose range

Penalized dose range

Penalized dose range

Introduction to IPSA
Anatomical Dose Prescription

Target

Bladder

Urethra

Rectum

DIL

Neuro-vascular bundles

Bulb

Etc.
Dose Constraints

- Urètre
- Lésion
- Vessie
- Rectum
- Prostate

```plaintext
GLOBAL DOSE PRESCRIPTION

TARGET
reference_target
ON   100 [ 950.0 1425.0 ] 100
IN    100 [ 950.0 1425.0 ] 30
dose  0.1
catheter 0.0

DUL
target
ON    0 [ 0.0 0.0 ] 0
IN    100 [ 1425.0 1425.0 ] 30
dose  0.0
catheter 0.0

URETHRA
organ_at_risk
ON    100 [ 950.0 1110.0 ] 30
IN    100 [ 950.0 1110.0 ] 30
dose  0.0
catheter 0.0

BULB
organ_at_risk
ON    0 [ 0.0 0.475.0 ] 20
IN    0 [ 0.0 0.475.0 ] 20
dose  0.0
catheter 0.0

RECTUM
organ_at_risk
ON    0 [ 0.0 0.475.0 ] 30
IN    0 [ 0.0 0.475.0 ] 30
dose  0.0
catheter 0.0

BLADDER
organ_at_risk
ON    0 [ 0.0 0.475.0 ] 20
IN    0 [ 0.0 0.475.0 ] 20
dose  0.0
catheter 0.0
```
Class Solution

- Prostate
- GYN template
- T&O
- Vaginal Cylinder
- Base of tongue
- Naso-pharynx
- Rectum
- Sarcomas
- Breast
- etc.

Same set of dose constraints for all patients
2- Optimization Engine: Simulated Annealing

Search of minimum
Performances and clinical examples

Comparison of Inverse Planning and Geometrical Optimization for Prostate HDR Brachytherapy
### G.O. + Manual

#### Target DVH

<table>
<thead>
<tr>
<th>Target</th>
<th>MANUAL</th>
<th>IPSA</th>
</tr>
</thead>
<tbody>
<tr>
<td>HI</td>
<td>0.57</td>
<td>0.72</td>
</tr>
<tr>
<td>V50 [%]</td>
<td>100.00</td>
<td>100.00</td>
</tr>
<tr>
<td>V75 [%]</td>
<td>98.31</td>
<td>100.00</td>
</tr>
<tr>
<td>V100 [%]</td>
<td>92.20</td>
<td>92.10</td>
</tr>
<tr>
<td>V120 [%]</td>
<td>70.07</td>
<td>51.05</td>
</tr>
<tr>
<td>V150 [%]</td>
<td>32.38</td>
<td>19.71</td>
</tr>
</tbody>
</table>

#### Rectum DVH

| V50 [%]| 17.05 | 11.54 |
| V75 [%]| 4.05  | 0.83  |
| V100 [%]| 0.44 | 0.00  |
| V120 [%]| 0.04 | 0.00  |
| V150 [%]| 0.00 | 0.00  |

#### Urethra DVH

| V50 [%]| 89.28 | 100.00 |
| V75 [%]| 78.14 | 90.74  |
| V100 [%]| 58.16 | 45.59  |
| V120 [%]| 30.85 | 0.98  |
| V150 [%]| 0.00  | 0.00  |

[Applicator diagram]
COVERAGE PRIORITIZED - HI, COIN

Homogeneity Index HI

IPSA

GO

Coformity Index COIN

p=0.005

GO HI

IPSA HI

GO COIN

IPSA COIN
Geo + Manual: 6 patients

45 minutes

Performance and clinical examples
IPSA : 20 patients

30 seconds

Performances and clinical examples
Protection of the bulb of the penis

Bulb CT contours from 17 patients

50% = 475cGy
Protection of the bulb of the penis

**Target DVH**
- **without protection**
  - V100: 96%
- **with protection**
  - V100: 94%

**Bulb of the penis DVH**
- 50% V100: 94%
- 100% V100: 96%

Average on 17 patients

- **BULB: V75 ↓ 80%**
- **TGT: V100 ↓ 2% (98->96%)**
Functional Imaging: MR–Spectroscopy
Display And Interpretation of Combined MRI/MRSI Data

Cancer

Normal

Overlaid Citrate Choline Images

MRSC/UCSF – Proton MRS Study

Patient ID: 35708642
Scan Date: 02/02/09
Image File: pc1500_B8824S3_div.int2
CST File: pc1500_b_cor_phased.complex
Slice 1: Posterior: 88.55
Slice 4: Posterior: 69.05

Selected Region: 61.48 cc
Size: 5.0 RL 20.0 AP 40.0 SI mm
CSF Resolution: 0.17 cc
Size: 7.0 RL 7.0 AP 3.5 SI mm

Slice 5: Posterior: 52.55
Slice 6: Posterior: 56.05
Slice 7: Posterior: 59.55
Slice 8: Posterior: 63.05

C>Cancer
H=Healthy
P=Possible C
M=Mixed
U=Unusable
Additional constraint: Boost within the prostate

MR Spectroscopy

Inverse Planned
Target -> 100 %
D.I.L. -> 120 %

Standard plan Geo + Manual

Target -> 100 %
D.I.L. -> 150 %

Performances and clinical examples
MRS-defined DIL Boost

<table>
<thead>
<tr>
<th></th>
<th>No Boost</th>
<th>B1</th>
<th>B2</th>
<th>B3</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>No Boost</td>
<td>120 - 150%</td>
<td>150 - 150%</td>
<td>150 - 170%</td>
</tr>
</tbody>
</table>
MRS-defined DIL Boost

0  No Boost
B1  120 - 150%
B2  150 - 150%
B3  150 - 170%

Bladder: V50(%)

Rectum: V50(%)

Urethra: V120(%)
Average V100(IPSA) = 94%
Where to put the catheters?
Emphasis on Target
Emphasis on Target
Bladder, Rectum, Bulb: Identical DVHs
How sensitive is the dosimetry of an implant to the number of catheters implanted?
How sensitive is the dosimetry of an implant when the catheter positions are optimized?
Freehand with TRUS Dental Putty Based Fixation
HDR Brachytherapy
IPSA in Plato BPS

- Prostate
- Prostate & penis
- Tandem & Ovoïd
- Breast
- Chest wall
- Rectum
- Vulve & uterus
- GYN interstitial
- Head and neck
- Nasopharinx
- Base of tongue
- Prostate & penis
Effect of dose constraint variations on a GYN-template
This graph shows the effect on the organ at risk protection when more emphasis is put on the coverage.

While the coverage approaches the 100% of the target volume, each organ at risk receives more dose.
Emphasis on Target
Emphasis on Target
<table>
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<tr>
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<th>IPSA</th>
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<tbody>
<tr>
<td>CTV V100</td>
<td>56 %</td>
<td>77 %</td>
</tr>
<tr>
<td>Soft palate</td>
<td>3.08 cc</td>
<td>3.55 cc</td>
</tr>
<tr>
<td>Nasa septum V100</td>
<td>1.65 cc</td>
<td>0.25 cc</td>
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</table>
# Breast Implant

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</tr>
</thead>
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<tr>
<td>CTV V100</td>
<td>93.8 %</td>
<td>93.8 %</td>
<td>90.0 %</td>
</tr>
<tr>
<td>CTV V150</td>
<td>18.4 %</td>
<td>14.7 %</td>
<td>12.0 %</td>
</tr>
<tr>
<td>Skin</td>
<td>-5 %</td>
<td>-8 %</td>
<td></td>
</tr>
<tr>
<td>Ribs</td>
<td>-5 %</td>
<td>-8 %</td>
<td></td>
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* Wierocik, Djay, Florida
Extrapolation to IORT
Emphasis on Target
Emphasis on Target
HDR Brachytherapy
IPSA

7 institutions
and more than 600 patients
treated since 2000

UCSF Comprehensive Cancer Center, San Francisco, USA
CHUQ Hôtel Dieu de Québec, Canada
National Institute of Health, Bethesda, USA
Centre Alexis Vautrin, Nancy, France
Toronto Sunnybrook Regional Cancer Center, Canada
CHUM Hôpital Notre-Dame, Montreal, Canada
Christiana Health Care, Newark, USA

Institut Gustave Roussy, Paris, France
...
User interface in SPOTpro 3.0

Class Solution

Permanent Prostate Implant

Prostate
Urethra
Bladder
Penile bulb
Rectum
Boost
**Additional options**

- Max number of needles
- Penalty per needle
- Max number of seeds
- Rapid Strand pattern only
- Max number of seeds in a row
- Min number of seeds per needle

**Permanent Prostate Implant**
Goal of the study:
- Define a Class solution
- that mimic an experienced dosimetrist

UCSF experience:
- More than 750 patients since 1996
- 95% biochemical disease-free survival (BDFS) after 5 years
- 1 dosimetrist
- Establishment of rules for manual pre-planning
46 cc

91 seeds 90 seeds
26 needles 23 needles
Prostate dosimetric indices

**DOSIMETRIST**

- $V_{100} = 99.6\%$
- $V_{150} = 61.4\%$
- $V_{200} = 26.1\%$
- $D_{90} = 177 \text{ cGy}$

**IPSA**

- $V_{100} = 99.7\%$
- $V_{150} = 61.4\%$
- $V_{200} = 25.5\%$
- $D_{90} = 173 \text{ cGy}$
Urethra dosimetric indices

DOSIMETRIST

V100 = 94.2%
V150 = 0.0%
D10 = 192 Gy

IPSA

V100 = 97.6%
V150 = 0.0%
D10 = 174 Gy
Seed loading pattern

2 seed outside the prostate
0 seed outside the prostate
1 needle with --------o-
0 needle with --------o-
4 needle with --ooo----
0 needle with --ooo----
Planning time

20 minutes for 1 dosimetrist

15 sec for 400,000 iterations (2.5 GHz PC)
DOSIMETRIST

Pre-planning

IPSA

Fast enough for Intra-operative pre-planning

Also designed for Live-planning
Dosimetric indices vs source activity

0.371 mCi
88 seeds

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## Dosimetric indices vs source activity

### Graph

- **Activities [mCi]**
  - Axes: Activities [mCi] vs number of seeds
  - Legends: Prostate v100 [%], Prostate v150 [%], Urethra v100 [%], Urethra v150 [%]

### Table: Dosimetric indices vs source activity with IPSA optimization

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**Image:**
- 0.4 mCi
- 80 seeds
Dosimetric indices vs source activity with IPSA optimization

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**Dosimetric indices vs source activity**

![Graph showing dosimetric indices vs source activity with IPSA optimization]

- **Activities [mCi]**: 0.3, 0.5, 0.7, 0.9
- **Number of seeds**: 56
- **Prostate v100 [%]**: 99.77
- **Prostate v150 [%]**: 54.27
- **Urethra v100 [%]**: 95.70
- **Urethra v150 [%]**: 0.02

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Dosimetric indices vs source activity

**Graph:**
- X-axis: Activities [mCi]
- Y-axis: Prostate v100 [%], Prostate v150 [%], Urethra v100 [%], Urethra v150 [%]
- Legend:
  - Blue line: number of seeds
  - Red line: Prostate v100 [%]
  - Orange line: Prostate v150 [%]
  - Green line: Urethra v100 [%]
  - Light green line: Urethra v150 [%]

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Dosimetric indices vs source activity

- Number of seeds vs Activities [mCi]
- Prostate v100 [%]
- Prostate v150 [%]
- Urethra v100 [%]
- Urethra v150 [%]

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0.8 mCi
43 seeds
Dosimetric indices vs source activity

![Graph and table showing dosimetric indices vs source activity with IPSA optimization.](image)

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<th>Activity [mCi]</th>
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<th>number of needles</th>
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<th>v150 [%]</th>
<th>Urethra v100 [%]</th>
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IPSA gives the ability to boost positive biopsies
IPSA gives the ability to boost positive biopsies
IPSA gives the ability to boost positive biopsies

\[ 150\% \leq \text{dose} \leq 200\% \]
IPSA gives the ability to boost positive biopsies

150% ≤ dose
IPSA gives the ability to boost positive biopsies

Without local boost

Positive biopsy boost

\[150\% \leq \text{dose} \leq 200\%\]

\[150\% \leq \text{dose}\]
Workload Shift

• Contour of anatomy
  – Reference target
  – Other Targets
  – Organs to protect

• Specification of Dose Constraints
  – No patient to patient adjustment needed
  – Library (class solution)

• Manual determination of active source positions

• Further dwell times adjustment

Performance and clinical examples
Dosimetric Advantages

- Better dose coverage on the target
- Better homogeneity index
- Takes into account all contoured targets and organs at risk
- Allows several targets, each with specific dose prescription
- Delivers dose distributions not considered before
Technical Advantages

- Optimization is achieved in a short time (20 to 50 s.)
- Automatically switches off the undesirable dwell-positions.
- No manual adjustment of dwell-times is required.
- Quality of planning is independent of the dosimetrist experience.
- Minimize the impact of misplaced catheters.
Summary

• If you can:
  – Define a Target
  – Insert enough catheters

• You can:
  – Obtain a conformal dose
  – Protect OAR
  – Be ready to treat in a short time
Thanks to

YongBok Kim, Ph.D.
John Kurhanewicz, Ph.D.
Cynthia Chuang, Ph.D.
Ping Xia, Ph.D.
Joyce Speight, M.D.

And
CHUQ-Quebec, NIH-Bethesda