Stereotactic Body Radiotherapy (SBRT) for Prostate Cancer: Practical Considerations for Treatment Planning

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Outline of Presentation

• Introduction
• Simulation and immobilization
• Treatment planning process
  – Target and OAR contours
  – Beam design
  – Dose optimization/calculation
  – Plan evaluation
• Patient treatment setup and verification
Learning Objectives

• Summarize and discuss the clinical issues involved when planning prostate patient with SBRT treatment including target volume delineation, contouring critical structure, dose prescription strategies, and plan evaluation

• Summarize and discuss the clinical issues associated plan simulation, motion management and treatment verification for prostate SBRT
# SBRT - Prostate

<table>
<thead>
<tr>
<th>Study</th>
<th>Schedule</th>
<th># of patients</th>
<th>Risk class</th>
<th>Medi F/U (mos)</th>
<th>Late grade 3 GU toxicity</th>
<th>Late grade 3 GI toxicity</th>
<th>FFBF</th>
</tr>
</thead>
<tbody>
<tr>
<td>CyberKnife</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Freeman, King, 2011 [6]</td>
<td>7-7.25 Gy in 5 fx</td>
<td>41</td>
<td>L</td>
<td>60</td>
<td>&lt; 1%</td>
<td>-</td>
<td>93% at 5 year</td>
</tr>
<tr>
<td>McBride et al. 2012 [7]</td>
<td>36.25-37.5 Gy in 5 fx</td>
<td>45</td>
<td>L</td>
<td>44.5</td>
<td>&lt; 1%</td>
<td>-</td>
<td>97.7% at 3 years</td>
</tr>
<tr>
<td>Fuller et al. [8]</td>
<td>38 Gy in 4 fx †</td>
<td>54</td>
<td>L-I</td>
<td>36</td>
<td>4%</td>
<td>-</td>
<td>96% at 3 years</td>
</tr>
<tr>
<td>Kang et al. [9]</td>
<td>32-36 Gy in 4 fx</td>
<td>44</td>
<td>L-I-H</td>
<td>40</td>
<td>-</td>
<td>-</td>
<td>100%, 100%, 90,9% at 5 years</td>
</tr>
<tr>
<td>King et al. 2012 [10]</td>
<td>36.25 Gy in 5 fx</td>
<td>67</td>
<td>L</td>
<td>32.4</td>
<td>3.5%</td>
<td>-</td>
<td>94% at 4 years</td>
</tr>
<tr>
<td>Gantry-based Systems</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Madsen et al. 2007 [11]</td>
<td>33.5 Gy in 5 fx</td>
<td>40</td>
<td>L</td>
<td>41</td>
<td>-</td>
<td>-</td>
<td>90% at 4 years</td>
</tr>
<tr>
<td>Boike et al. 2011 [12]</td>
<td>45-50 Gy in 5 fx</td>
<td>45</td>
<td>L-I</td>
<td>30, 18, 12</td>
<td>4%</td>
<td>2% plus 1 Grade 4</td>
<td>100% at 1–2.5 years</td>
</tr>
</tbody>
</table>

**Abbreviations:** L = low; I = intermediate; H = high.

Alongi et al. Radiation Oncology 2013, 8:171
Common treatment techniques

- Isocenter
  - Isocentric (Linac gantry based) vs. non-isocentric (Cyberknife)

- Beam arrangement
  - Coplanar vs. non-coplanar beams
  - Static gantry angle IMRT vs. Volumetric arc modulated treatment (VMAT)

- PTV dose distribution
  - Homogenous vs. Heterogeneous vs. Simultaneous boost
Isocentric vs. non-isocentric

Courtesy of BrainLab®

Courtesy of Accuray®
PTV dose coverage

Uniform distribution

D. B. FULLER et al., IJROBP. V70(5), 2008

Clinical Workflow

- Patient immobilization and simulation
- Target and organ at risk (OAR) delineation
- Isocenter placement and beam design
- Dose optimization and calculation
- Plan evaluation and quality assurance
- Patient setup and verification
- Treatment delivery
Special considerations - Challenges

• Close proximity of OARs
• High dose gradient / conformity
• Organ motion
Patient immobilization

Vacuum bag

Body frame
CT simulation

- Placement of 3 gold markers via trans-rectal ultrasound
- Patient instructed to have comfortably full bladder
- Patient in supine position in the immobilization device
- Non-contrast CT scan and MRI of the pelvis
  - from above the iliac crest to below the ischium
  - 1.5mm slice thickness
Rectal Balloon

Both S etc. TCR, Vol.1(3), 2012

Spacer between Prostate and Rectum

- Biocompatible liquid gel injected between the prostate and rectum under ultrasound guidance

Alongi et al. Radiation Oncology 2013, 8:171
Target localization

MRI Prostate Anatomy Atlas:  http://www.prostadoodle.com/
OAR contours

- Bladder
- Rectum
- Penile bulb
- Femoral heads
- Urethra (optional)
- Bowel (optional)
- Testes (optional)
# Planning dose constraints

<table>
<thead>
<tr>
<th></th>
<th>HDR</th>
<th>San Diego</th>
<th>UCSF</th>
<th>Erasmus</th>
<th>UCLA</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total dose</strong></td>
<td>19 Gy</td>
<td>38 Gy</td>
<td>19 or 38 Gy</td>
<td>38 Gy</td>
<td>36.25 Gy</td>
</tr>
<tr>
<td><strong>Fractions</strong></td>
<td>2</td>
<td>4</td>
<td>2 or 4</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td><strong>Prescription</strong></td>
<td>&gt;50%</td>
<td>&gt;60%</td>
<td>&gt;67%</td>
<td>88%-92%</td>
<td></td>
</tr>
<tr>
<td><strong>PTV margin</strong></td>
<td>none</td>
<td>2-5 mm/0 post.</td>
<td>2 mm/0 post.</td>
<td>3 mm/0 post.</td>
<td>5 mm/3 mm post.</td>
</tr>
<tr>
<td><strong>PTV</strong></td>
<td>V100% a ≥90%</td>
<td>V100% a ≥95%</td>
<td>V100% a ≥95%</td>
<td>V100% a ≥95%</td>
<td>V100% a ≥95%</td>
</tr>
<tr>
<td><strong>Rectum</strong></td>
<td>V75% a &lt;1 cc</td>
<td>Wall V100% a = 0</td>
<td>V75% a &lt;2 cc</td>
<td>Wall V100% a = 0</td>
<td>V50% a &lt;50% V80% a &lt;20%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Mucosa b V75% a = 0</td>
<td>V90% a &lt;10% V100% a &lt;5%</td>
</tr>
<tr>
<td><strong>Bladder</strong></td>
<td>V75% a &lt;1 cc</td>
<td>V120% a = 0</td>
<td>V75% a &lt;3 cc</td>
<td>V110% a = 0 V100% a &lt;1 cc</td>
<td>V50% a &lt;40% V100% a &lt;10%</td>
</tr>
<tr>
<td><strong>Urethra</strong></td>
<td>V125% a &lt;1 cc</td>
<td>V120% a = 0</td>
<td>V120% a &lt;10%</td>
<td>V120% a = 0</td>
<td>V100% a &lt;10%</td>
</tr>
</tbody>
</table>

---

*a Vxx: Volume of structure (PTV or organ at risk) receiving xx% of prescription dose.
*b Mucosa: solid structure formed by a 3 mm contraction of the rectal wall.

Descovich et al. JACMP Vol. 14 (5), 2013
Dose conformity and Homogeneity

Conformity index\textsubscript{RTOG} = \frac{V_{RI}}{TV}

Conformation number (CN) = \frac{TV_{RI}}{TV} \times \frac{TV_{RI}}{V_{RI}}

Fig. 1. Four possibilities for which the $V_{RI}/TV$ ratio is equal to 1 (index proposed by the RTOG) (1) (target volume, shaded; volume of reference isodose, enclosed in black dashes).

Feuvret L. et. al., IJROBP, V64(2), 2006
Cyberknife plan

- Typical treatments consist of about 100-120 non-coplanar beams
- Total treatment 40-60 minutes
- Imaging correction every 5–7 beams (about every 30–90s)

Chen et al. Radiation Oncology 2013, 8:58
Cyberknife vs. Linac IMRT

- No posterior beams in cyberknife plan. More anterior beams transvers the bladder
  - Higher bladder dose
- Fewer beams to enter from the left side of patient due to the robotic kinematic constraints
  - Higher dose to right femur compared with left femur

Pawlicki et al. Med Dosi 32(2), 2007
Cyberknife vs. Linac IMRT

Table 1. Conformity index and homogeneity index values for each patient for CK SBRT and simulated IMRT plans

<table>
<thead>
<tr>
<th>Pt. No.</th>
<th>Volume (cm³)</th>
<th>CI</th>
<th>CK SBRT</th>
<th>IMRT</th>
<th>ΔCI%</th>
<th>HI</th>
<th>CK SBRT</th>
<th>IMRT</th>
<th>ΔHI%</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>138.0</td>
<td>1.13</td>
<td>1.24</td>
<td>-8.87</td>
<td>1.33</td>
<td>1.18</td>
<td>12.71</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>95.6</td>
<td>1.31</td>
<td>1.41</td>
<td>-7.09</td>
<td>1.35</td>
<td>1.31</td>
<td>3.05</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>67.3</td>
<td>1.11</td>
<td>1.58</td>
<td>-29.75</td>
<td>1.39</td>
<td>1.38</td>
<td>0.72</td>
<td></td>
<td></td>
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<tr>
<td>4</td>
<td>64.0</td>
<td>1.11</td>
<td>1.52</td>
<td>-26.97</td>
<td>1.67</td>
<td>1.30</td>
<td>28.46</td>
<td></td>
<td></td>
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<tr>
<td>5</td>
<td>41.7</td>
<td>1.13</td>
<td>1.41</td>
<td>-19.86</td>
<td>1.39</td>
<td>1.27</td>
<td>9.45</td>
<td></td>
<td></td>
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<tr>
<td>6</td>
<td>40.0</td>
<td>1.16</td>
<td>1.54</td>
<td>-24.68</td>
<td>1.41</td>
<td>1.30</td>
<td>8.46</td>
<td></td>
<td></td>
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<tr>
<td>7</td>
<td>36.2</td>
<td>1.20</td>
<td>1.35</td>
<td>-11.11</td>
<td>1.49</td>
<td>1.20</td>
<td>24.17</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>28.0</td>
<td>1.30</td>
<td>1.45</td>
<td>-10.34</td>
<td>1.56</td>
<td>1.27</td>
<td>22.83</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>60.9</td>
<td>1.18</td>
<td>1.44</td>
<td>-17.33</td>
<td>1.45</td>
<td>1.28</td>
<td>13.73</td>
<td></td>
<td></td>
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<tr>
<td>SD</td>
<td>37.1</td>
<td>0.08</td>
<td>0.11</td>
<td>9.03</td>
<td>0.12</td>
<td>0.06</td>
<td>10.28</td>
<td></td>
<td></td>
</tr>
<tr>
<td>p</td>
<td>&lt;.01</td>
<td>.01</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

S. Hossain et al. IJROBP.78(1), 2010
All beams:
10–30% isodose through testes
Testicular mean dose: approx. 6.6 Gy

Excluding direct beams:
3% isodose skims testes
Testicular mean dose: approx. 1.3 Gy

King. Front Radiat Ther Oncol. V43. 2011
Volumetric Modulated Arc for SBRT

• Volumetric arc modulated therapy that simultaneously changes:
  – Gantry rotation speed
  – Treatment aperture shape (MLC)
  – Delivery dose rate

• Improved conformity

• Fast plan delivery
Linac VMAT and IMRT plan
Beam parameter selection

• Prostate SBRT plans developed for different number of arcs collimator angels, beam energies and couch rotations for ten patients
  – Plans with $\pm 45^\circ$ collimator angles required 38% less MU with no collimator rotations and 20% less than $\pm 22.5^\circ$
  – Plans with $\pm 45^\circ$ collimator angles provided more homogeneous dose distribution
  – Plans with two arcs provided improved conformity and homogeneity compared with single arc

Agazaryan N. et al. ASTRO 2010
Beam parameter selection

- Increasing the number of arcs to 3 did not provide significant improvement
- $\pm 5^\circ$ couch rotations between arcs did not improve the plan dosimetry significantly
- Selection of beam energy between 6MV and 10MV did not show notable dosimetric difference

Agazaryan N. et al. ASTRO 2010
Current planning protocol

- Prescription: 8Gy x 5 fractions
- Beam energy: 6MV SRS (1000MU/Minute)
- Arc: 2 full arcs split to 4 half arcs
- Collimator rotation: ±45°
- No couch rotation
Plan optimization

- **Goals:**
  - **PTV:**
    - $V_{100} \geq 95\%$  $R_{50} < 4.0$
  - **Rectum:**
    - $V_{20Gy} < 50\%$  $V_{32Gy} < 20\%$
    - $V_{36Gy} < 10\%$  $V_{40Gy} < 5\%$
  - **Bladder:**
    - $V_{20Gy} < 40\%$  $V_{40Gy} < 10\%$
  - **Femur header:**
    - $V_{16Gy} < 5\%$
Flattering Filter Free (FFF)
MLC Size

Standard MLC

HD120 MLC
Plan evaluation - where you stand?

Table II. Plan quality statistics pre- and postincorporation of the new plan into the cohort of 32 existing plans.

<table>
<thead>
<tr>
<th>Clinical variable</th>
<th>Stat. based on existing plans</th>
<th>Stat. upon new plan incorporation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>25% quantile</td>
<td>Median</td>
</tr>
<tr>
<td>PTV</td>
<td></td>
<td></td>
</tr>
<tr>
<td>V38</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>V20/VPTV</td>
<td>3.15</td>
<td>3.25</td>
</tr>
<tr>
<td>Rectum</td>
<td></td>
<td></td>
</tr>
<tr>
<td>V520</td>
<td>20%</td>
<td>25%</td>
</tr>
<tr>
<td>V32</td>
<td>6%</td>
<td>7%</td>
</tr>
<tr>
<td>V36</td>
<td>3.5%</td>
<td>4%</td>
</tr>
<tr>
<td>V40</td>
<td>0</td>
<td>1%</td>
</tr>
<tr>
<td>Bladder</td>
<td></td>
<td></td>
</tr>
<tr>
<td>V20</td>
<td>9.5%</td>
<td>17%</td>
</tr>
<tr>
<td>V40</td>
<td>1%</td>
<td>2%</td>
</tr>
<tr>
<td>Left femoral</td>
<td></td>
<td></td>
</tr>
<tr>
<td>V16</td>
<td>0</td>
<td>1%</td>
</tr>
<tr>
<td>Right femoral head</td>
<td></td>
<td></td>
</tr>
<tr>
<td>V16</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Ruan et. al. Medical Physics, Vol. 39(5), 2012
A diagram illustrates the treatment planning process. The process begins with the Planner, which leads to Treatment Planning. The Planning Scripts (Parser) are then updated with the Patient plan database and Published standards. The Plan Quality Report includes Planning goals, achieves, and ranks. If the Plan Evaluation is Yes, it progresses to Physics Check QA. Otherwise, it involves Re-plan.
## ProstateSBrt Plan Quality Report

**ProstateSBrt Plan Quality Report**

<table>
<thead>
<tr>
<th>Structure</th>
<th>End Point</th>
<th>Ideal</th>
<th>Acceptable</th>
<th>Output</th>
<th>Mean</th>
<th>StdDev</th>
<th>25 Pctl</th>
<th>Median</th>
<th>75 Pctl</th>
<th>Suggestion</th>
</tr>
</thead>
<tbody>
<tr>
<td>P_Prit</td>
<td>V100%</td>
<td>≥ 95%</td>
<td></td>
<td>95.13%</td>
<td>95.12%</td>
<td>0.20%</td>
<td>95.00%</td>
<td>95.14%</td>
<td>95.28%</td>
<td>Acceptable</td>
</tr>
<tr>
<td>P_Prit</td>
<td>V50%/Vol</td>
<td>≤ 4</td>
<td></td>
<td>3.50</td>
<td>3.37</td>
<td>0.13</td>
<td>3.28</td>
<td>3.35</td>
<td>3.43</td>
<td>Acceptable</td>
</tr>
<tr>
<td>O_Rctm</td>
<td>V50%</td>
<td>≤ 50%</td>
<td></td>
<td>20.98%</td>
<td>20.89%</td>
<td>3.78%</td>
<td>17.80%</td>
<td>20.24%</td>
<td>24.20%</td>
<td>Acceptable</td>
</tr>
<tr>
<td>O_Rctm</td>
<td>V80%</td>
<td>≤ 20%</td>
<td></td>
<td>8.96%</td>
<td>6.67%</td>
<td>2.65%</td>
<td>4.78%</td>
<td>5.56%</td>
<td>8.96%</td>
<td>Acceptable</td>
</tr>
<tr>
<td>O_Rctm</td>
<td>V90%</td>
<td>≤ 10%</td>
<td></td>
<td>5.73%</td>
<td>4.09%</td>
<td>1.92%</td>
<td>2.58%</td>
<td>3.23%</td>
<td>5.73%</td>
<td>Acceptable</td>
</tr>
<tr>
<td>O_Rctm</td>
<td>V100%</td>
<td>≤ 5%</td>
<td></td>
<td>2.23%</td>
<td>1.37%</td>
<td>0.65%</td>
<td>0.86%</td>
<td>2.23%</td>
<td></td>
<td>Acceptable</td>
</tr>
<tr>
<td>O_Bldr</td>
<td>V50%</td>
<td>≤ 40%</td>
<td></td>
<td>19.52%</td>
<td>14.87%</td>
<td>8.81%</td>
<td>8.69%</td>
<td>14.35%</td>
<td>17.11%</td>
<td>Acceptable</td>
</tr>
<tr>
<td>O_Bldr</td>
<td>V100%</td>
<td>≤ 10%</td>
<td></td>
<td>2.99%</td>
<td>3.06%</td>
<td>1.98%</td>
<td>1.78%</td>
<td>2.59%</td>
<td>3.23%</td>
<td>Acceptable</td>
</tr>
<tr>
<td>O_FeImp_R</td>
<td>V40%</td>
<td>≤ 5%</td>
<td></td>
<td>0.26%</td>
<td>0.52%</td>
<td>0.94%</td>
<td>0.00%</td>
<td>0.00%</td>
<td>0.52%</td>
<td>Acceptable</td>
</tr>
<tr>
<td>O_FeImp_L</td>
<td>V40%</td>
<td>≤ 5%</td>
<td></td>
<td>0.63%</td>
<td>1.53%</td>
<td>3.89%</td>
<td>0.00%</td>
<td>0.00%</td>
<td>0.31%</td>
<td>Acceptable</td>
</tr>
</tbody>
</table>
Patient Treatment Setup and Verification

- Patient inter-fractional positioning correction:
  - 2D image pairs (OBI, ExacTrac …)
  - 3D volumetric image (CBCT)

- Patient intra-fractional motion tracking:
  - Electromagnetic tracking (Calypso)
  - Stereoscopic imaging (ExacTrac)
Replay: Fusion & Shift Detection

Overlay Mode
- X-Ray
  - Add
  - Amber/Blue
  - Subtract
  - Spyglass
- DRR

Shift
- Vertical: 5.06, 0.07
- Longitudinal: -0.15, -0.27
- Lateral: -0.62, -2.83

Marker Detection
- Automatic
- Reset Fusion

Marker
- 1/3
- Delete
- Define
- Shift pattern
- Reset

Please detect and fuse implanted markers.
Prostate moves!

Courtesy of ViewRay®
Intra-fractional motion

“If large movements (>5mm) could be excluded by some active correction strategies, then the average V100% for the simulated plan could be restored to within approximately 2% of the ideal treatment plans.”

Hossain et al., Med. Phys. 35 (9), 2008
Agazaryan N. et al. ASTRO 2010
MRI guided radiotherapy

Courtesy of ViewRay®
References


Summary | Conclusion

- Hypofractionation has the potential to biologically dose-escalate radiotherapy for prostate cancer.
- Establishing SBRT procedures and guidelines from CT simulation to treatment planning, verification, delivery, and reporting methodology is essential to the success of the implementation of prostate SBRT treatment.
- Personal training is another important aspect of implementation of a SBRT prostate program.
Acknowledgements

Christopher King, MD, PhD
Patrick Kupelian, MD
Michael Steinberg, MD
Daniel Low, Ph.D.
Nzhde Agazaryan, Ph.D.
John DeMarco, Ph.D.
Steve Tenn, Ph.D.
Dan Ruan, Ph.D.
Ke Sheng, Ph.D.
Chul Lee, M.S.