Brachytherapy Physics

Prostate
Prostate Brachytherapy
Permanent Seed Prostate Brachytherapy (LDR)
Needle types
- Loose Seeds loaded manually into needles
- Mick Application
- RapidStrand (I-125) or stranded needles

Physics guidelines require 10% seed assay

Data
## Prescribed Dose

<table>
<thead>
<tr>
<th></th>
<th>Previous</th>
<th>Current*</th>
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<tbody>
<tr>
<td><strong>I-125</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Monotherapy</td>
<td>160 Gy</td>
<td>145 Gy</td>
</tr>
<tr>
<td>+ 45 Gy EBRT</td>
<td>120 Gy</td>
<td>108 Gy</td>
</tr>
<tr>
<td><strong>Pd 103</strong></td>
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<td></td>
</tr>
<tr>
<td>Monotherapy</td>
<td>115 Gy</td>
<td>120 Gy</td>
</tr>
<tr>
<td>+ 45 Gy EBRT</td>
<td>90 Gy</td>
<td>95 Gy</td>
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</table>

*Current prescriptions require seeds to be calibrated to current national standards and have current dosimetric data.

Recommendations of the American Association of Physicists in Medicine regarding the Impact of Implementing the 2004 Task Group 43 Report on Dose Specification for $^{103}$Pd and $^{125}$I Interstitial Brachytherapy

It is important to keep an eye on the prescribed dose and the dosimetric data used to calculate such prescribed dose. *Especially for PD-103.*
TABLE I. Equipment requirement for the prostate seed implant program.

<table>
<thead>
<tr>
<th>Capital equipment</th>
<th>Pre-loaded needle technique</th>
</tr>
</thead>
<tbody>
<tr>
<td>Well-type ionization chamber</td>
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</tr>
<tr>
<td>GM or scintillation detector</td>
<td>GM or scintillation detector</td>
</tr>
<tr>
<td>Ion chamber survey meter</td>
<td>Ion chamber survey meter</td>
</tr>
<tr>
<td>Computer treatment planning system</td>
<td>Computer treatment planning system</td>
</tr>
<tr>
<td>Ultrasound unit</td>
<td>Ultrasound unit</td>
</tr>
<tr>
<td>Stabilization device/attachment</td>
<td>Stabilization device/attachment</td>
</tr>
<tr>
<td>Fluoroscopy unit</td>
<td>Fluoroscopy unit</td>
</tr>
<tr>
<td>Mick applicator</td>
<td></td>
</tr>
</tbody>
</table>

| Supplies and consumables                      |                                                     |
| Loading block, cartridges                     | Needle box, (optional) needle loading device        |
| Seed carrier                                  | Seed sterilization container                         |
| Mick-compatible needles                       | Needles                                             |
| (Optional) stabilization needles              | (Optional) stabilization needles                     |
| Reverse action tweezers                       | Reverse action tweezers                              |
| Radioactive seeds                             | Radioactive seeds                                    |
| Spacers and bone wax                          |                                                     |
Patient Selection- Definitive Treatment

• Primary
  – Gleason Score $\leq 6$
  – PSA $\leq 10$ ng/mL
  – Stage $\leq T2a$

• Secondary
  – 3 or fewer cores
  – No positive seminal vesicles or distant mets.
  – Prostate volume $\leq 60$ cc
    • Pubic arch interference
    • Urinary retention
  – TURP discouraged
  – disease limited to the gland
  – Expected life $>5$ yrs
Sources

I-125

- **Advantages**
  - Well characterized dosimetry
  - Long term use

- **Disadvantages**
  - Relatively long half-life
  - Rounded seed ends make them mobile
  - Very anisotropic dose distribution

Pd-103

- **Advantages**
  - Short half-life
  - Cupped seed ends tend to anchor seeds

- **Disadvantages**
  - Dosimetry based on only two studies
  - Activity decays 4% a day
  - Edema not resolved for 30 days, may cause issues with implants

-- Both are NIST traceable and have rapid strands available
Characteristics of $^{125}$I

- Energy of emitted photons - keV (number of photons per decay):
  - $27.4 \pm 1.15$, $31.4 \pm 0.25$, $35.5 \pm 0.067$
- Outer Dimension: 4.5 mm x 0.8 mm
- Half Life: 59.4 Days
- Typical Prescription 145 Gy
  (160 Gy using 1985 dosimetry standards)
- Initial dose rate = 7.0 cGy/hr
- 90% of total dose delivered in 197 days
- HVL in tissue = 1.8 cm
- Exposure rate at 1 m from the patient < 0.3 mR/hr
Characteristics of $^{103}$Pd

- Energy of principal emitted photons -keV (number of photons per decay): 20.1 (0.656), 23.0 (.125)
- Outer Dimension: 4.5 mm x 0.81 mm
- Half Life: 16.97 Days
- Typical prescription 120 Gy
- Initial dose rate = 19.6 cGy/hr
- 90% of total dose delivered in 56 days
- HVL in tissue = 1.1 cm
- Exposure rate at 1 m from the patient < 0.15 mR/hr
Schematic Diagram of $^{125}\text{I}$
6711 Seed

- I-125 adsorbed on silver rod
- 0.05 mm titanium
- 0.8 mm
- 30 mm
- 4.5 mm
Schematic Diagram of $^{103}$Pd Seed

- Titanium end cup
- Pd plated graphite pellet (.9 mm L x 6 mm D)
- Laser weld
- Titanium tube
- Lead X-ray marker (1.0 mm L x .5 mm D)

Dimensions:
- 0.8 mm
- 4.5 mm
\(^{125}\)I 6711 Seed Prostate Implant Radiograph
$^{103}\text{Pd}$ Prostate Implant Radiograph
Ultrasound images

- urethra
- anterior part of rectal wall
- rectum
- prostate
- possible seed positions
Ultrasound images
Avoiding the pubic arch: change probe angle or hyper-extend legs
Treatment Planning Goals

• Provide coverage of the entire target volume
• Limit rectal and urethral doses to acceptable limits
• Minimize dose inhomogeneity
• Plan for possible pubic arch interference
• Design the implant as technically simple as possible
Seed Distribution

• Uniform Loading
• Peripheral Loading
• Modified Peripheral Loading
Uniform Loading

- Classic approach of spacing seeds 1 cm apart throughout the prostate
- Requires a higher number of lower strength seeds
  - 0.30 to 0.39 mCi/seed for $^{125}$I
  - 0.93 to 1.16 mCi/seed for $^{103}$Pd
- Relatively high doses in the center of the prostate
Peripheral Loading

• An alternative approach in which seeds are preferentially limited to the periphery of the prostate
• Requires a substantial increase in seed strength
  – 0.60 to 0.80 mCi/seed for $^{125}$I
  – 1.5 mCi/seed or higher for $^{103}$Pd
• The end result is to produce a dose minimum, instead of a dose maximum, at the location of urethra
Peripheral Loading
Modified Peripheral Loading

• Some seeds in the central portion of a uniformly loaded implant are deleted to reduce central dose
• Strength/seed higher than with uniform loading
Modified Peripheral Loading
Critical Structures

- Seeds should not be placed in close proximity to the urethra.
- The aim should be to cover the entire prostate while keeping the dose to the rectal wall as small as possible.
- Rectal dose can be high, especially if peripheral loading is employed using higher activity seeds.
Dose Reporting Parameters

- $D_{100}$, $D_{90}$, $D_{80}$ - dose to 100%, 90%, 80% of the target volume for dosimetric evaluation
- $V_{200}$, $V_{100}$, $V_{90}$, $V_{80}$ - (fractional) volume of the prostate target that received 200%, 100%, 90%, 80% of the prescribed minimum peripheral dose
- DVH
Treatment Volumes
MIR and Seattle

- GTV = Prostate(MIR) and/or P and SV(Seattle)
- PTV = GTV + 3-5mm(R,L,A) and 0-3mm post

PTV use encouraged to cover for possible extra capsular disease
Acceptable Dose Distribution

PTV:
V 100 > 95%
V 150 < 40%
V 200 < 20%

Prostate:
V 100 > 99%

Urethra Point: 100-125% KEEP<150%

Rectum Point: <100%

Margin
Post-Implant Dosimetry Evaluation

• CT-Based Dosimetry:
  – Current standard of practice
  – Allows quantitative evaluation (DVH, mPD, etc)
  – Operator dependence can be minimized
  – Allows quick identification of inadequate implants (for example systematically missing the base of prostate in seed insertion)
  – Allows secondary dosimetric effects to be considered (anisotropy)
  – Allows inhomogeneity correction
Postimplant Dosimetry
Postimplant Dosimetry
<table>
<thead>
<tr>
<th>Needle Number</th>
<th>Retraction (cm)</th>
<th>Hole Location</th>
<th>Number Seeds</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.00</td>
<td>b4.0</td>
<td>3</td>
</tr>
<tr>
<td>2</td>
<td>0.00</td>
<td>c4.0</td>
<td>3</td>
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<tr>
<td>3</td>
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<td>d4.0</td>
<td>3</td>
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<tr>
<td>4</td>
<td>0.00</td>
<td>e4.0</td>
<td>3</td>
</tr>
<tr>
<td>5</td>
<td>0.50</td>
<td>C3.5</td>
<td>4</td>
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<tr>
<td>6</td>
<td>0.50</td>
<td>E3.5</td>
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<tr>
<td>7</td>
<td>0.00</td>
<td>b3.0</td>
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<tr>
<td>8</td>
<td>0.00</td>
<td>c3.0</td>
<td>3</td>
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<tr>
<td>9</td>
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<td>0.00</td>
<td>e3.0</td>
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<tr>
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### Retraction Legend

<table>
<thead>
<tr>
<th>Plane 0</th>
<th>Plane 1</th>
<th>Plane 2</th>
<th>Plane 3</th>
<th>Plane 4</th>
<th>Special</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00 cm</td>
<td>0.50 cm</td>
<td>1.00 cm</td>
<td>1.50 cm</td>
<td>2.00 cm</td>
<td>other</td>
</tr>
</tbody>
</table>

### Plan Summary

- **Total Activity [U]**: 43.74
- **Total Activity [mCi]**: 34.44
- **Total Needles**: 28
- **Total Seeds**: 88
- **Extra Seeds**: None
- **Total Seeds to Order**: None
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</table>
In The OR
In The OR
Sources of Dosimetric Uncertainties

- Seed displacement
  - source-to-source spacing differences
  - needle placement errors
  - seed splaying
- Prostate edema postimplantation
- Difficulty in defining the target volume based on CT
- Patient positioning reproducibility (volume study and operating room)
  - ONLY BENEFIT OF ONLINE PLANNING
- Prostate volume changes between volume study and implant
  - especially important in the case of hormones therapy
- Prostate movement during implantation, even with stabilizing needles in place
Pre Plan-Prostate LDR QA

- Treatment Planning System QA
  - Study data input geometric accuracy
  - Accuracy of Dosimetric Data of Sources
  - Dose Calculation Accuracy against manual TG43
    - Single and dual source configurations
- QA on instrumentation for Data Acquisition and implantation
  - Ultrasound QA
    - Transverse Positional Accuracy
    - Sagittal Positional Accuracy
    - Image Quality (TGC) and effects on positional accuracy
  - Appropriate template selection
- Plan Evaluation QA
  - Appropriate Data set used and registered to template
  - Appropriate Prescription and source selection
  - Appropriate needle, source and Dose Distributions based on guidelines
- Plan Loading QA
  - Source Strength Verification
    - NIST Calibrated source to determine Well Chamber Calibration Factors
    - Assay 10% of sources
  - Source Tracking During sterilization
  - Needle Loading
    - Autoradiograph of needles compared against plan data
    - Procedures for Source Accountability storage and recordkeeping
- Post Implantation QA
  - Seed Accountability
  - Radiation Safety : Patient and Area Survey
HDR Prostate Brachytherapy
HDR Prostate - Seattle

- Mate *et al*, IJROBP 1998 41(3): 525-533
  - HDR brachytherapy at 3.0 Gy – 4.0 Gy x 4, followed by 50.4 Gy external beam treatments
  - Ultrasound guided-needle insertion
  - CT-based optimization of HDR dwell times
    - CT gantry tilted to be orthogonal to needle paths
  - Peripherally weighted dose distribution
    - Less than 120% dose to urethra
HDR Prostate – William Beaumont Hospital

- HDR boost treatment
  - Kini et al, IJROBP 1999 43(3): 571-578
  - 50 Gy external beam
  - 2 factions HDR brachytherapy at 9.5 Gy/tx given at 1st and 3rd week of external beam treatments

- HDR alone treatment
  - Martinez et al, IJROBP 2001 49(1): 61-69
  - 36 Gy in 4 fractions
  - BID in two days
  - Considered to be equivalent to 76.4 Gy external beam dose