Brachytherapy for the Treatment of Prostate Cancer

Yakov Pipman, D.Sc.
Long Island Jewish Medical Center
Clinical Considerations

- Prostate Cancer grows slowly
- Early detection is more common
- Larger Doses are required to control Prostate tumors
- Life expectancy is longer
- Quality of life is affected by side effects and complications
The most common treatments for prostate cancer include:

- surgery

- external beam radiotherapy (EBRT)

- hormone therapy

- radioactive seed implants (TPPI)

- watchful waiting.
Main Modalities for Prostate RT

- **External Beam Radiation Therapy**
  - Classical 2-D planning
  - 3D-Conformal RT (3D-CRT)
  - IMRT

- **Permanent Implants**
  - Nomogram and rule based
  - Preplanned and preloaded
  - Intraoperative Interactive dose planned

- **HDR Brachytherapy**
It is what lays around the prostate that affects the limits of RT
Fig. 2. Logistic response models for bNED for two pretreatment PSA groups.

From: G.E. Hanks et. al., IJROBP, June 2000
Fig. 5. Logistic response models for gastrointestinal and genitourinary radiation sequelae.
Spatial Relations between Volumes typical of EBRT

- **Sensitive Organ I**
- **Sensitive Organ II**
- **PTV**
- **CTV**
- **GTV**
- **TREATED (50% Isodose)**

95%
Stages amenable to Brachytherapy

- **T1** - The tumor is located within the prostate gland and is too small to be detected by DRE. It may be discovered through other diagnostic procedures (PSA test, biopsy). Generally produces no Physical symptoms.

- **T2 Stage** - The tumor is still located within the prostate gland but it can be felt during a DRE exam or imaged by ultrasound or MR.
Sources of uncertainty in EBRT that can be avoided in Brachytherapy

- Physiological movements and variations in size, shape and position of the Prostate gland in relation to anatomic landmarks or an internal reference point. The CTV is expanded by the Internal Margins (IM) to create the Internal Target Volume (ITV).

- Typically Internal Margins are:
  - A: 5 mm posterior
  - B: 10 mm anterior and lateral, and
  - C: Two slices each, superior and inferior, “copied” from the last delineated axial level. Slices are 3 mm apart so the IM=6 mm.
Prostate seed implants

- Prostate implants were developed in the 1960’s at Memorial Sloan Kettering Cancer Center and on the West coast. The initial technique involved open access to the prostate.
- On the last fifteen years, Transperineal prostate implants became predominant in the USA, pioneered by SPI - Washington State, Mt Sinai and MSKCC in NY.
- More than 800 papers published on this subject since 1990.
Transrectal Ultrasound Guided Brachytherapy
- High Lithotomy
- Patient to edge of table
- Symmetry of legs
- Tilt US forward to remove air from the bladder
Different implant techniques
The American Brachytherapy Society (ABS) recommends an RX of 145 Gy and 125 Gy for $^{125}\text{I}$ and $^{103}\text{Pd}$, in monotherapy brachytherapy, and 110 Gy of $^{125}\text{I}$ and 100 Gy $^{103}\text{Pd}$ if used as a boost following pelvic EBRT of 40 to 50 Gy.

Typically the doses are prescribed to the minimum peripheral dose (MPD) which is the maximum dose that cover 100% of the target volume. Usu. 90% of the target volume will receive the prescription dose.
The Mean Peripheral dose is the average of the dose at the surface of the target volume, and varies less than the MPD with seed position.
Iodine 125 \(^{125}I\) and Palladium 103 \(^{103}Pd\) are the most commonly used isotopes.

Properties:

\begin{align*}
\text{Iodine 125} & : \\
\text{Palladium 103} & : \\
\end{align*}

- **Half life (d)**: 59.4 17
- **Energy (kV)**: 28 21
- **Radiobiologic Equiv.**: 1.4 1.9
125 I model 6711

103 Pd model 200

Titanium end cup

Pd plated graphite pellet (0.9 mm L x 0.6 mm D)

Laser weld

Titanium tube

Lead X-ray marker (91.0 mm L x 0.5 mm D)

0.8 mm

4.5 mm

3.0 mm

0.50 mm

0.05 mm Titanium

125 I adsorbed on silver core
Radial Dose Functions

- MED3633
- Mdl 200, TG43
- Mdl 200, Meigooni, et al.
- Mdl 200, Chiu-Tsao & Anderson
- Mdl 200, Luxton
- Mdl 200, Fontenla, et al.
- Mdl 200, Sahoo & Anderson
- Mdl 200, Russell

Y-axis: $g(r)$
X-axis: $r$, cm
Advantages of seed implants:

- Recent clinical data shows a high percentage of implant patients remaining disease free than with either radical prostatectomy or external beam therapy.

- Seed implantation normally takes about one or two hours. The patient usually leaves the hospital the same day. Many patients resume normal activities within a few days.

- Seeds can deliver two to three times more dose than EBRT.

- Incontinence occurs in less than 5% of patients under the age of 60. More often for patients over the age of 60.

- This procedure is better tolerated than surgery or external radiation.
Disadvantages of seed implants:

- The long term results are fully established yet. The current clinical data show good results up to seven years.

- It is common to experience problems with urination for several months after seed implantation. These symptoms will, however, gradually ease and eventually disappear.

- Although the seeds remain radioactive for several months, the energy and activity of the seeds is so low that there is negligible risk of exposure to others and only simple precautions are necessary for the first 2-3 months.
1. **RTOG 98-05:**
   “Phase II Trial of TRUS Permanent Radioactive Implantation of the Prostate for the Definitive Management of Localized Adenocarcinoma of the Prostate.”

2. **American Brachytherapy Society:** “*The ABS Recommendations for Permanent Prostate Brachytherapy Post implant Dosimetric Analysis*” *Int.J.Radiat Oncol Biol Phys, 2000;46,N 1:221-230*”
RTOG Objectives

- Evaluate effectiveness of TRUS permanent implantation of the prostate for organ confined adenocarcinoma as compared with historical data of prostatectomy or external beam.
- Establish & Test QA standards for future protocols.
- Test dosimetric evaluation of implants.
**RTOG Parameters:**

- Criteria for Patient Selection.
- Definition of Planning Target Volume: $(PTV = \text{Pre-implant TRUS} + \text{margins})$
- Evaluation Target Volume $(ETV = \text{Post-Op CT})$.
- Seed Calibration and Handling.
- Post-Op evaluation.
- Dose Volume Histogram.
Evaluation criteria

- **Per Protocol**: ≥ 80% of ETV receives at least 90% of PD.

- **Variation, Acceptable**: ≥ 50% of the ETV receives at least 90% of PD.

- **Deviation, Unacceptable**: ≥ 50% of the ETV receives <90% of PD.
**Iodine-125 Properties**

I-125 sealed in metal *seed*
Average energy = 28 keV,

**Patient Dose:**
(Assuming 145 Gy isodose at the surface of the prostate of diameter = 5cm)
Average Dose Rate = 7cGy/hour = 168 cGy/day
(Similar to external beam therapy).
Total dose (calculated for Half Life x 1.44)

Total Dose = 7 cGy x 24 hour x 60 days x 1.44

= 14,500 cGy = 145 Gy

Shielding

Half Value Layer = 0.025 mm lead = 20 mm tissue. So, 10 cm of tissue attenuates 97% of x-rays.

External Exposure

Pelvic surface = 2 - 20 mrem/hour

Three foot distance = 0.1 -> 1 mrem/hour

Background = 2 mrem/week
- **Pre-planning (PP):** Creation of a plan a few days or weeks before implant procedure.
- **Intra-operative Planning (IOP):** Tx Planning in the OR: Pt and TRUS probe are not moved between the volume study and the seed insertion.
- **Interactive Planning (IP):** Stepwise refinement of the Tx plan using computerized dose calculations derived from image-base needle position feedback.
- **Dynamic Dose Calculation (DDC):** Constant updating of dose distribution calculations using continuous feedback.
- Used for most RTPS.
- It eliminates the need to determine the orientation of the source longitudinal axis from imaging studies.

General 1-D formalism

1-D isotropic point source calculation

\[ \dot{D}(r) = S_x \cdot \Lambda \cdot \frac{G_X(r, \theta_0)}{G_X(r_0, \theta_0)} \cdot g_X(r) \cdot \phi_{ax}(r) \]

1D anisotropy function

\[ \phi_{ax}(r) = \frac{\int_0^\pi \dot{D}(r, \theta) \sin(\theta) \, d\theta}{2 \, D(r, \theta_0)} \]
Source $^{125}$I [STM 1251] [NIST 99]

Radial Dose Function, source description and anisotropy factor (Variseed)
- **Source** $^{125}\text{I}$ [6711] [NIST 99]
- **Radial Dose Function and Anisotropy Factor**
"Each institution planning to provide brachytherapy should have the ability to independently verify the source strength provided by the manufacturer". (TG-40).

- The Medical Physicist (MP) should independently measure 10% of the sources to be implanted in the patient (TG-56).
- The MP is responsible for the dose given to the patient.

Figure 1a: Surface contour plot of an American model 8731 LDR 192Ir source made with an isocenterPhotograph.

Figure 1b: Surface contour plot of a North American isocentric model 500151-1-A5.5-11Ir source made with an isocenterPhotograph.

Ionization Chamber and inserts for single seed and cartridge
Acquisition and contouring of US images in OR Planning
In OR Planning

- Seed placement and plan evaluation (100%, 150% and 200% isodoses displayed)

Dosimetric Quality Alerts:
- Prostate - D90 is less than or equal to 115.0% of Prescription Dose
- Urethra - D30 is less than or equal to 150.0% of Prescription Dose
- Rectum - D100 is less than or equal to 50.0% of Prescription Dose
- Rectum - V100 is less than or equal to 1.3 cc
Post-Implant CT-based evaluation
Post-Implant CT-based evaluation
3-D graphical representation of post implant evaluation.
LIJ Post-Implant, Ct-based, DVH Evaluation

Dose Volume Histogram Window

Dose vs. Normalized Volume Graph

Current Region of Interest: prostate
Trial: Trial_1
Beam: All Beams/Sources
Color: purple
% Outside Grid: 0.00%
% > Max: 6.68%
NTCP/TCP:

Current Region of Interest: urethra
Trial: Trial_1
Beam: All Beams/Sources
Color: green
% Outside Grid: 0.00%
% > Max: 0.00%
NTCP/TCP:

Current Region of Interest: bladder
Trial: Trial_1
Beam: All Beams/Sources
Color: blue
% Outside Grid: 0.00%
% > Max: 0.00%
NTCP/TCP:

Current Region of Interest: rectum
Trial: Trial_1
Beam: All Beams/Sources
Color: yellow
% Outside Grid: 0.00%
% > Max: 0.00%
NTCP/TCP:
Prostate Tissue Coverage - Preplanned and Preloaded Needle Technique

Percent of Volume

90% of PD
### Areas of Sensitive Organ Surfaces Receiving High Doses-LIJ

<table>
<thead>
<tr>
<th>Case Number</th>
<th>Rectal Wall Above 200GY</th>
<th>Bladder Wall Above 150 Gy</th>
<th>Urethral Wall Above 300Gy</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.9</td>
<td>6.4</td>
<td>2.9</td>
</tr>
<tr>
<td>2</td>
<td>0.5</td>
<td>0.3</td>
<td>0.1</td>
</tr>
<tr>
<td>3</td>
<td>0.0</td>
<td>0.2</td>
<td>0.0</td>
</tr>
<tr>
<td>4</td>
<td>2.6</td>
<td>1.5</td>
<td>2.0</td>
</tr>
<tr>
<td>5</td>
<td>4.7</td>
<td>6.2</td>
<td>3.1</td>
</tr>
<tr>
<td>6</td>
<td>6.1</td>
<td>3.6</td>
<td>2.6</td>
</tr>
<tr>
<td>7</td>
<td>0.3</td>
<td>0.2</td>
<td>0.2</td>
</tr>
<tr>
<td>8</td>
<td>0.2</td>
<td>0.3</td>
<td>0.7</td>
</tr>
<tr>
<td>9</td>
<td>0.1</td>
<td>0.0</td>
<td>0.1</td>
</tr>
<tr>
<td>10</td>
<td>18.5</td>
<td>13.4</td>
<td>13.4</td>
</tr>
<tr>
<td>11</td>
<td>9.4</td>
<td>9.4</td>
<td>9.4</td>
</tr>
<tr>
<td>12</td>
<td>3.6</td>
<td>3.6</td>
<td>3.6</td>
</tr>
<tr>
<td>13</td>
<td>1.3</td>
<td>1.2</td>
<td>1.2</td>
</tr>
<tr>
<td>14</td>
<td>0.7</td>
<td>0.8</td>
<td>0.8</td>
</tr>
</tbody>
</table>

**Legend:**
- Rectal Wall Above 200GY
- Bladder Wall Above 150 Gy
- Urethral Wall Above 300Gy
Prostate Tissue Coverage - Nomogram and Loose Seed Technique

- Prescription dose
- 90% of PD
- 80% of PD
## Dosimetric Comparison of techniques

<table>
<thead>
<tr>
<th></th>
<th>Preplan + Preload</th>
<th>Nomogram + Loose Seeds</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>AVERAGE</td>
<td>St.Dev.</td>
</tr>
<tr>
<td>% Prostate Volume Covered by the Prescription Dose</td>
<td>93.4</td>
<td>4.9</td>
</tr>
<tr>
<td>% Prostate Volume Covered by 90% of the Prescription</td>
<td>95.9</td>
<td>3.5</td>
</tr>
<tr>
<td>% Prostate Volume Covered by 80% of the Prescription</td>
<td>97.5</td>
<td>2.4</td>
</tr>
</tbody>
</table>
Fig. 3. Actuarial PSA relapse-free survival for patients treated with iodine divided by the dose cutoff value of the D90 dose <90%, ≥90% of the prescribed dose (p = 0.04) (Solid line, D90 ≥90% of the prescribed dose; dashed line, D90 <90% of the prescribed dose).
Table 6. Actuarial 48-month PSA-RFS comparing the D90 dose
<90% or ≥90% of the prescribed dose for Pd-103, I-125, TIPPB as monotherapy, and TIPPB combined with EBT

<table>
<thead>
<tr>
<th>Factor</th>
<th>D90 dose</th>
<th>4-yr. PSA-RFS</th>
<th>n</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Palladium</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;90</td>
<td>83.4</td>
<td>178</td>
<td></td>
<td>.01</td>
</tr>
<tr>
<td>≥90</td>
<td>93.3</td>
<td>423</td>
<td></td>
<td>.04</td>
</tr>
<tr>
<td>Iodine</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;90</td>
<td>63.8</td>
<td>38</td>
<td></td>
<td>.04</td>
</tr>
<tr>
<td>≥90</td>
<td>93.0</td>
<td>80</td>
<td></td>
<td>.001</td>
</tr>
<tr>
<td>No hormones</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;90</td>
<td>81.0</td>
<td>134</td>
<td></td>
<td>.001</td>
</tr>
<tr>
<td>≥90</td>
<td>93.4</td>
<td>335</td>
<td></td>
<td>.001</td>
</tr>
<tr>
<td>Hormones</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;90</td>
<td>79.3</td>
<td>82</td>
<td></td>
<td>.001</td>
</tr>
<tr>
<td>≥90</td>
<td>92.5</td>
<td>168</td>
<td></td>
<td>.13</td>
</tr>
<tr>
<td>EBT + TIPPB</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;90</td>
<td>87.9</td>
<td>77</td>
<td></td>
<td>.13</td>
</tr>
<tr>
<td>≥90</td>
<td>88.23</td>
<td>122</td>
<td></td>
<td>.001</td>
</tr>
<tr>
<td>TIPPB alone</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;90</td>
<td>74.3</td>
<td>136</td>
<td></td>
<td>.001</td>
</tr>
<tr>
<td>≥90</td>
<td>94.6</td>
<td>384</td>
<td></td>
<td>.001</td>
</tr>
</tbody>
</table>
Permanent Prostate Brachytherapy
Real-Time Dosimetry Algorithm

Anesthesia
Lithotomy Position

Ultrasound Placement

Peripheral and Central Needle Placement

Image Capture at 5mm steps
Prostate Contouring

Inverse Planning

Acceptable Parameters

Mick loading of needles

Realtime Assessment
Implanted and planned sources create a real-time composite of prostate doses

Completion of the case and dosimetric parameters are documented

Needle adjustment can be performed for each iteration of the inverse plan until an acceptable plan is approved.

If the real-time D90 dose falls by 5% at anytime during the case, a new iteration is performed relative to implanted and pending sources.
Mick Needle

3 Implanted Sources

2 pending source locations

Real-time update of dose parameters
The learning curve...
# Needle Loading Report

## VariSeed: Needle Loading Report [Page 1]

5/29/2003: 14:43 PM

### Table of Needle Loading

<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>D5.0</td>
<td>5</td>
</tr>
<tr>
<td>2</td>
<td>0.00</td>
<td>E5.0</td>
<td>5</td>
</tr>
<tr>
<td>3</td>
<td>0.00</td>
<td>F5.0</td>
<td>5</td>
</tr>
<tr>
<td>4</td>
<td>0.00</td>
<td>G5.0</td>
<td>5</td>
</tr>
<tr>
<td>5</td>
<td>0.50</td>
<td>A4.5</td>
<td>5</td>
</tr>
<tr>
<td>6</td>
<td>0.50</td>
<td>B4.5</td>
<td>5</td>
</tr>
<tr>
<td>7</td>
<td>1.00</td>
<td>C4.0</td>
<td>3</td>
</tr>
<tr>
<td>8</td>
<td>0.00</td>
<td>D4.0</td>
<td>2</td>
</tr>
<tr>
<td>9</td>
<td>0.00</td>
<td>E4.0</td>
<td>2</td>
</tr>
<tr>
<td>10</td>
<td>0.00</td>
<td>F4.0</td>
<td>5</td>
</tr>
<tr>
<td>11</td>
<td>0.00</td>
<td>G4.0</td>
<td>5</td>
</tr>
<tr>
<td>12</td>
<td>1.00</td>
<td>A3.0</td>
<td>5</td>
</tr>
<tr>
<td>13</td>
<td>0.50</td>
<td>B3.5</td>
<td>5</td>
</tr>
<tr>
<td>14</td>
<td>0.50</td>
<td>C3.5</td>
<td>5</td>
</tr>
<tr>
<td>15</td>
<td>1.00</td>
<td>D3.0</td>
<td>3</td>
</tr>
<tr>
<td>16</td>
<td>0.00</td>
<td>E3.0</td>
<td>5</td>
</tr>
<tr>
<td>17</td>
<td>0.00</td>
<td>F3.0</td>
<td>5</td>
</tr>
<tr>
<td>18</td>
<td>0.00</td>
<td>G3.0</td>
<td>5</td>
</tr>
<tr>
<td>19</td>
<td>0.00</td>
<td>A2.0</td>
<td>5</td>
</tr>
<tr>
<td>20</td>
<td>1.00</td>
<td>B2.5</td>
<td>5</td>
</tr>
<tr>
<td>21</td>
<td>0.50</td>
<td>C2.5</td>
<td>5</td>
</tr>
<tr>
<td>22</td>
<td>0.50</td>
<td>D2.5</td>
<td>5</td>
</tr>
<tr>
<td>23</td>
<td>1.00</td>
<td>E2.0</td>
<td>3</td>
</tr>
<tr>
<td>24</td>
<td>0.00</td>
<td>F2.0</td>
<td>5</td>
</tr>
<tr>
<td>25</td>
<td>0.00</td>
<td>G2.0</td>
<td>5</td>
</tr>
<tr>
<td>26</td>
<td>0.00</td>
<td>H2.0</td>
<td>5</td>
</tr>
<tr>
<td>27</td>
<td>0.00</td>
<td>J2.0</td>
<td>3</td>
</tr>
<tr>
<td>28</td>
<td>1.00</td>
<td>K2.0</td>
<td>3</td>
</tr>
</tbody>
</table>

### Retraction Legend

- **0.00 cm**
- **0.50 cm**
- **1.00 cm**
- **1.50 cm**
- **2.00 cm**
- **Other**

### Table of Plan Summary

<table>
<thead>
<tr>
<th>Number of Needles</th>
<th>Seeds per Needle</th>
<th>Total Activity [mCi]</th>
<th>Total Seeds</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>2</td>
<td>52.70</td>
<td>122</td>
</tr>
<tr>
<td>8</td>
<td>3</td>
<td>41.50</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>5</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Special Loading

- **Needle 5**

---

Report of Needle Loading

Long Island Jewish Medical Center

VariSeed 7.1 (Build 2348)

D41F C194-515B18938BM2 AE2548

Study Created by __________________________

Study Approved by _________________________
Post Implant dosimetry-finding the seeds
Dose display for evaluation and reporting
HDR Brachytherapy for Prostate

- Used as boost to 45 Gy EBRT
- HDR dose given in 2 fractions of 8 Gy each
- EBRT given after HDR
- Gold markers placed at base and at apex
Dose equivalence for complete RT course

- \( \text{ERD} = d \left\{ 1 + \frac{d}{(\alpha/\beta)} \right\} \)
- for \( (\alpha/\beta) = 1.5 \)
- \( \text{ERD(HDR)} = 8 \{ 1 + \frac{8}{1.5} \} = 50 \text{ Gy} \)
- Total dose = 2x50+45=145 Gy

(similar to seed implant with I-125)
Planning Procedure

- CT based anatomy delineation
- Catheter tracking
- Inverse planning
- Review and adjustment of isodose distribution
- Manual adjustment of dwell times
Catheter tracks with prospective dwell positions
Dose cloud at 8 Gy covers the Prostate tightly.
The Rectum and Bladder are easily spared.
2-D dose distribution display.

The prostate is well covered by the 8 Gy isodose. The maximum dose to the urethra is 130%.
Pre-implant plan DVH evaluations

**DVH_0**: Cumulative DVH on target. State: Consistent.

**DVH_5**: Cumulative DVH on urethra. State: Consistent.

**DVH_1**: Cumulative DVH on bladder wall. State: Consistent.

**DVH_3**: Cumulative DVH on rectal wall. State: Consistent.
Large number of source dwell positions offers great flexibility for Optimizing the Dose

<table>
<thead>
<tr>
<th>Offset (mm)</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
<th>14</th>
<th>15</th>
<th>16</th>
<th>17</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
</tr>
<tr>
<td>1.0</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
</tr>
<tr>
<td>2.0</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
</tr>
<tr>
<td>3.0</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
</tr>
</tbody>
</table>

Steps size: 2.5, 5.0, 10.0 mm
**Prostate Brachytherapy**

**DVH evaluation**

**Permanent seed implant**

**LDR**

**HDR with remote afterloader**

Long Island Jewish Medical Center

North Shore LIJ Health System
Comparison of Biological Effectiveness for all Four Modalities

<table>
<thead>
<tr>
<th>Modality</th>
<th>Fractionation</th>
<th>Total Dose (Gy)</th>
<th>BED (Gy)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I-125</td>
<td>1 x 144</td>
<td>144.0</td>
<td>123</td>
</tr>
<tr>
<td>EBRT</td>
<td>44 x 1.8</td>
<td>79.2</td>
<td>170</td>
</tr>
<tr>
<td>EBRT</td>
<td>25 x 1.8</td>
<td>45.0</td>
<td>99</td>
</tr>
<tr>
<td>I-125</td>
<td>1 x 115</td>
<td>115.0</td>
<td>98</td>
</tr>
<tr>
<td>EBRT + I-125</td>
<td>1 x 115</td>
<td>115.0</td>
<td>197</td>
</tr>
<tr>
<td>EBRT</td>
<td>25 x 1.8</td>
<td>45.0</td>
<td>99</td>
</tr>
<tr>
<td>HDR</td>
<td>2 x 8</td>
<td>16.0</td>
<td>101</td>
</tr>
<tr>
<td>EBRT + HDR</td>
<td>2 x 8</td>
<td>16.0</td>
<td>200</td>
</tr>
</tbody>
</table>