BRACHYTHERAPY BASICS

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DISCLOSURES

• None
OUTLINE

- Intro to brachytherapy basics
- Breast brachy
- Gynecologic brachy
- Prostate brachy

BRACHYTHERAPY:
TREATING FROM INSIDE OUT

Brachytherapy provides
- Radiation that is close to or within the tumor
- High dose to target volume
- Sharp dose fall-off

External beam therapy works from the outside → in
Brachytherapy works from the inside → out
THE EVOLUTION OF BRACHYTHERAPY

1901
Brachytherapy first used for lupus and malignancies1,2

1917
Techniques developed for prostate cancer3

1950s-1960s
New sources, techniques, and equipment reduced patient and physician exposure to radiation leading to a renaissance for brachytherapy4

Ongoing
Accepted as an important treatment option with strong supporting data for numerous cancers1-8

1903
Brachytherapy first used for gynecologic cancers4

1920s
Brachytherapy widely used to treat accessible tumors with radium5

1970s
Brachytherapy established as safe and standard-of-care for gynecologic cancers6

1950s-1960s
New sources, techniques, and equipment reduced patient and physician exposure to radiation leading to a renaissance for brachytherapy1

1970s
Brachytherapy established as safe and standard-of-care for gynecologic cancers6

BROAD CLINICAL UTILITY OF BRACHY

Most common uses
SPECIALIZED APPLICATORS AND AFTERLOADER MATCHED TO TREATMENT NEEDS

- Gynecologic
- Breast
- Skin
- Lung
- Prostate

Afterloader

INTRACAVITARY BRACHYTHERAPY APPLICATIONS

- Applicators are placed adjacent to the tumor
- Additional needles can provide coverage outside of target area
- Useful for following body sites
  - Gynecologic – cervical, endometrial, vaginal
  - Rectum
  - Nasopharynx
  - Breast (post procedure)
INTERSTITIAL BRACHYTHERAPY APPLICATIONS

- Catheters are placed into the lesion and adjacent tissue
- Useful for following body sites
  - Prostate
  - Breast
  - Head and neck
  - Bladder
  - Brain

INTRALUMINAL BRACHYTHERAPY APPLICATIONS

- Applicators are placed adjacent to the tumor
- Useful for following body sites
  - Lung
  - Esophagus
  - Biliary
SURFACE BRACHYTHERAPY APPLICATIONS

- Applicators are placed on the skin
- Useful for treatment of keloids and some types of skin cancer

BRACHYTHERAPY WORKFLOW

- Applicator placement
- Simulation
- Catheter reconstruction
- Target/OAR contouring
- Planning
- Treatment
TEMPLATE MAPPING AND APPLICATOR DIGITIZATION

CATHETER RECONSTRUCTION

Single Channel

Multiple Channels
IMAGE TECHNIQUES AND FUSION

- **CT or MR based planning?**
  - Image fusion can be difficult
  - Applicator/Catheter digitization can be tricky
  - Plan can be created on CT or MR when using TG43 calculations

TARGET/OAR/CATHETER 3D RECONSTRUCTION

Images courtesy of UCSF

Target and OAR reconstruction

Inclusion of catheters and possible dwell positions

Images courtesy of UCSF
INVERSE PLANNING SIMULATED ANNEALING

Images courtesy of UCSF

PLAN OPTIMIZATION AND REVIEW

- Scripting
- Plan Quality Report
- OAR constraints
- External Beam Radiation considerations (EQD2)
HIGH DOSE RATE (HDR) BRACHYTHERAPY – REMOTE AFTERLOADING

The radiation strength is proportional to dwell time

BREAST BRACHYTHERAPY
APBI RATIONALE

- **Oncologic**
  - Majority of failures are true recurrences (around where tumor started)
  - Not clear that treating the whole breast reduces elsewhere failures

- **Convenience**
  - Treatment can be completed within 1 week

- **Toxicity**
  - Improved breast cosmesis
  - Decreased organs at risk dose (heart/lung)
WHO IS A CANDIDATE?

Accelerated Partial Breast Irradiation: Executive summary for the update of an ASTRO Evidence-Based Consensus Statement

Candace Correa MD #, Eleanor E. Harris MD #, Maria Cristina Leonardi MD #, Benjamin D. Smith MD #, Alphonse G. Taghian MD, PhD *, Alastair M. Thompson MD #, Julia White MD #, Jay R. Harris MD #,*

Table 1: Comparison of patient groups in original and updated consensus statements

<table>
<thead>
<tr>
<th>Patient group</th>
<th>Risk factor</th>
<th>Original</th>
<th>Update</th>
</tr>
</thead>
<tbody>
<tr>
<td>Suitability</td>
<td>Age</td>
<td>≥60 y</td>
<td>≥60 y</td>
</tr>
<tr>
<td></td>
<td>Margins</td>
<td>Negative by at least 2 mm</td>
<td>No change</td>
</tr>
<tr>
<td></td>
<td>T stage</td>
<td>T1</td>
<td>T1 or T2</td>
</tr>
<tr>
<td></td>
<td>DCIS</td>
<td>Not allowed</td>
<td>All allowed:</td>
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Brain Radio Oncology (2017) 9, 73-79

WHOLE BREAST VS APBI (CAVITY + MARGIN)
APBI TECHNIQUES

- **Interstitial tube and button**
  - treatment 2 times per day for 8-10 treatments
  - some early data to support just 3 treatments

- **Single entry catheter devices**
  - treatment 2 times per day for 8-10 treatments
  - some early data to support just 3 treatments

- **External beam radiation**
  - treatment 2 times per day for 10 treatments or daily for 10 treatments
  - Treatment 1 time per day for 5 treatments

INTERSTITIAL BREAST
3D Dosimetry Distribution

SINGLE-ENTRY CATHETER DEVICES

MammoSite  MammoSiteML  Contura  SAVI
EXAMPLE OF SINGLE ENTRY CATHETER

B39 CONTOURING GUIDELINES

**Brachytherapy**
- **IS** – 1.5 cm expansion on cavity
- **Balloon** – 1.0 cm expansion on cavity
- **EBRT** – 1.5 cm CTV expansion and 1.0 cm PTV expansion

**EBRT**
- Planning Target Volume (PTV) includes chest wall and musculocutaneous fat.
- Planning Target Volume (PTV) excludes chest wall and musculocutaneous fat.
- Clinical Target Volume (CTV) includes chest wall and musculocutaneous fat.
SAVI DIAGRAM

PRESCRIPTION

- **Brachy**
  - 3.4 Gy x 10
  - 4 Gy x 8
  - 7.0-7.5 Gy x 3 (early data)
- **EBRT**
  - 3.85 Gy x 10
  - 4 Gy x 10
  - 6 Gy x 5
- **IORT**
  - Xoft 20 Gy x 1 to the balloon surface
**DOSE CONSTRAINTS FOR APBI**

<table>
<thead>
<tr>
<th>Table 2. Target volume and organ at risk constraints for applicator APBI</th>
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</thead>
<tbody>
<tr>
<td><strong>B39 Interstitial</strong></td>
</tr>
<tr>
<td>$D_{90}$</td>
</tr>
<tr>
<td>Breast $V_{150}$</td>
</tr>
<tr>
<td>Breast $V_{200}$</td>
</tr>
<tr>
<td>Skin $D_{\text{max}}$</td>
</tr>
<tr>
<td>Chest wall $D_{\text{max}}$</td>
</tr>
</tbody>
</table>

SAVI = strut-adjusted volume implant, $D_{90}$ = the percentage of the prescribed dose received by 90% volume of the prostate, $V_{150}$ = the percentage of the prostate volume receiving 150% of the prescribed dose or more, $V_{200}$ = the percentage of the prostate volume receiving 200% of the prescribed dose or more, $D_{\text{max}}$ = maximum dose, $cc$ = cm$^3$


**BREAST PQR**

**TARGET: $D_{90}$, $V_{150}$, $V_{200}$**

**OARS: SKIN, CHEST WALL, LUNG**

33

34
INTRA-OPERATIVE RADIATION THERAPY

- 1 treatment
- In the operating room
- While you are asleep
- In theory you wake up “done” with radiation

IORT Treatment Options

**TARGET**
- 50 kV x-ray
- 20 Gy at surface, 5-7 Gy at 1 cm
- 20-45 min treatment time

**Electronic Brachy**
- 50 kV electronic brachy
- 20 Gy at surface
- 10-20 min treatment time

**ELIOT**
- 4-12 MeV
- 21 Gy to 90%
- 3.5 min treatment time
Unacceptable Cosmesis in a Protocol Investigating Intensity-Modulated Radiotherapy With Active Breathing Control for Accelerated Partial-Breast Irradiation


International Journal of Radiation Oncology * Biology * Physics
Volume 76, Issue 1, Pages 71-78 (January 2010)
DOI: 10.1016/j.ijrobp.2009.01.041
Visible impairment in cosmesis observed in 3 patients deemed to have unacceptable cosmesis after treatment.

Distribution of the proportion of the breast reference volume in each case receiving 50% of prescribed dose (V50), by cosmetic outcome.
Whole breast V5 <70%, V50 <40%, V80 <25-30%, V100 <15-18%

EBRT APBI

- Can be done safely now with increased attention to spill dose to rest of breast
GYNECOLOGIC BRACHYTHERAPY

CERVICAL CANCER
~12,000 NEW CASES & 4,000 DEATHS PER YEAR

Cervical Cancer
Incidence Rates* by State, 2014†

Range
- Data not available
- 4.6 to 6.2
- 6.3 to 7.5
- 7.6 to 8.7
- 9.0 to 10.4
TREATMENT OVERVIEW

STANDARD OF CARE (SOC): EBRT + CHEMO + BRACHY

EBRT
5 weeks
Mon-Fri
20 min daily

Brachy
4 treatments
2 per week

Weekly Cisplatin
40 mg/m²
5-6 cycles

Complete all treatment within 8 weeks
**ARE WOMEN RECEIVING SOC: EBRT + CHEMO + BRACHY?**

**NCDB analysis**

- 15,200 pts
- 2004-2012
- Only 44% received SOC

**NCDB analysis**

![Graph showing percent survival over months for different treatment combinations](image)

- Improved OS w/ SOC

**REDUCTION IN OS WITHOUT THE USE OF BRACHYTHERAPY**

![Graph showing proportion of use of IMRT/SBRT boost](image)

- INC IN USE OF IMRT/SBRT BOOST

![Graph showing adjusted overall survival over time](image)

- DEC IN OVERALL SURVIVAL

**References**

- Gill B et al. IJROBP. 2014.
WHY IS BRACHYTHERAPY SO IMPORTANT?
LOCATION, LOCATION, LOCATION

• Inside out approach with brachy allows:
  • Higher dose to the tumor
  • Less dose to the bladder, rectum/sigmoid, and small bowel

MOVING FROM 2D FLUOROSCOPY TO 3D CT/MRI BASED PLANNING
2D PLANNING

Where is the tumor?
Where is the rectum/sigmoid/bladder?

PROBLEM WITH POINT BASED RX

TUMOR UNDER VS OVER COVERAGE

POINTS CAN UNDERESTIMATE DOSE TO BLADDER AND RECTUM
NATIONAL TREND TOWARDS VOLUME BASED TREATMENTS

A

<table>
<thead>
<tr>
<th></th>
<th>2007</th>
<th>2014</th>
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<tbody>
<tr>
<td>X ray</td>
<td>43%</td>
<td>15%</td>
</tr>
<tr>
<td>CT</td>
<td>15%</td>
<td>55%</td>
</tr>
<tr>
<td>MRI</td>
<td>95%</td>
<td>2%</td>
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B

<table>
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<tr>
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<th>2007</th>
<th>2014</th>
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<tbody>
<tr>
<td>HRCTV</td>
<td>52%</td>
<td>14%</td>
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<tr>
<td>Point A</td>
<td>76%</td>
<td>42%</td>
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STANDARDIZING VOLUME BASED DEFINITIONS

- White – Gross disease (GTV)
- Yellow – High Risk Target (HR-CTV)
- Orange – Intermediate Risk Target (IR-CTV)
The 6 steps of IGRT

Slide adapted from Richard Potter

VOLUME VS POINT BASED PRESCRIPTION

YELLOW LINE – 100% of dose
LIMITATIONS OF STANDARD 3 CHANNEL APPLICATORS

3 channels adequate
3 channels NOT adequate
Coverage adequate with more channels

Red – tumor
Orange – 100% radiation dose

APPLICATORS THAT ALLOW NEEDLES

Syed/MUPIT
Vienna
Utrecht
EXAMPLE OF HOW EXTRA NEEDLES IMPROVE TUMOR COVERAGE

CERVICAL CANCER PLANNING GOALS

- HR-CTV 80-85 Gy (D90 > 85 Gy)
  - Most commonly after 45 Gy, 6 Gy x 5 or 7 Gy x 4
- Rectum D2cc < 65 Gy (ideal), < 75 Gy (max)
- Bladder D2cc < 80 Gy (ideal), < 90 Gy (max)
- Sigmoid/Bowel D2cc < 70 Gy (ideal)
**Biologically Equivalent Dose**

*Equivalent Dose in 2 Gy Fractions (EQD2)*

\[ \text{BED} = nd \left( 1 + d / \alpha / \beta \right) / \left( 1 + 2 / \alpha / \beta \right) \]

\[ \text{EQD2} = \text{BED} / 1.2 \]

- \( n \) = # fractions
- \( d \) = dose/fraction
- \( \alpha / \beta \) for tumor \( \sim 10 \)
- \( \alpha / \beta \) for normal tissue \( \sim 3 \)

**Example:**

\[ (5 \text{ fractions}) \times (5.5 \text{ Gy}) \times (1+5.5 \text{ Gy/10}) / 1.2 = 35.5 \text{ Gy}_{10} \]

---

**Physical - Biological Documentation of Gynaecological HDR BT**

<table>
<thead>
<tr>
<th>PATIENT</th>
<th>ID-number</th>
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**EXTERNAL BEAM THERAPY**

<table>
<thead>
<tr>
<th>dose per fraction</th>
<th>D_{50} (Gy)</th>
<th>D_{90} (Gy)</th>
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</thead>
<tbody>
<tr>
<td>Factions without central shield</td>
<td>12.0</td>
<td>12.0</td>
</tr>
<tr>
<td>Factions with central shield</td>
<td>12.0</td>
<td>12.0</td>
</tr>
<tr>
<td>Total dose</td>
<td>12.0</td>
<td>12.0</td>
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</table>

**BRACHYTHERAPY**

<table>
<thead>
<tr>
<th>Date</th>
<th>Time</th>
<th>Fraction</th>
<th>Dose (Gy)</th>
<th>Notes</th>
</tr>
</thead>
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**GTV (cm³)**

- D 100 = 60 Gy
- D 90 = 50 Gy
- D 50 = 30 Gy
- V 90 = at least 90%
VAGINAL CYLINDERS

Most common indication:
Post-op Endometrial

Defining prescription
Where do you prescribe?

Fixed prescription at depth of 0.5cm (100%)
Range of dose at surface

Fixed dose at surface (100%)
Range of dose at 0.5cm

DOSE
60-70%
100%
140-170%

Slide courtesy of Manjeet Chadha
Defining prescription length

Active Source length
The distance along which the source dwell times are calculated.

Treatment length
The Sup-Inf. distance of the prescription isodose in target

<table>
<thead>
<tr>
<th>HER</th>
<th>Active length</th>
<th>Treatment length</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.0 cm</td>
<td>3.0 cm</td>
<td></td>
</tr>
<tr>
<td>3.0 cm</td>
<td>4.7 cm</td>
<td></td>
</tr>
<tr>
<td>4.0 cm</td>
<td>5.9 cm</td>
<td></td>
</tr>
</tbody>
</table>

Slide courtesy of Manjeet Chadha

Vaginal brachytherapy for postoperative endometrial cancer:
2014 Survey of the American Brachytherapy Society
Matthew M. Harkenrider1,2, Sarbhi Grover1, Beth A. Erickson1, Akila N. Viswanathan1, Christina Small1, Stephanie Kliethermes3, William Small Jr1

“When delivering vaginal brachytherapy do you most commonly prescribe dose to a fixed or fractional length of the vagina?”

<table>
<thead>
<tr>
<th>Length of proximal vagina treated</th>
<th>Percentage</th>
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</thead>
<tbody>
<tr>
<td>Fixed length (61.4%)</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>25.4</td>
</tr>
<tr>
<td>4</td>
<td>48.6</td>
</tr>
<tr>
<td>5</td>
<td>24.3</td>
</tr>
<tr>
<td>Other</td>
<td>1.7</td>
</tr>
<tr>
<td>Fractional length (35.4%)</td>
<td></td>
</tr>
<tr>
<td>Proximal 1/3</td>
<td>26.0</td>
</tr>
<tr>
<td>Proximal 1/2</td>
<td>64.0</td>
</tr>
<tr>
<td>Entire vagina</td>
<td>1.0</td>
</tr>
<tr>
<td>Other</td>
<td>9.0</td>
</tr>
<tr>
<td>Other (3.2%)</td>
<td></td>
</tr>
</tbody>
</table>

2014 Survey VBT Alone Doses
- 7.0 Gy for 3 ft to 0.5 cm
- 6.0 Gy for 5 ft to VS
- 5.5 Gy for 4 ft to 0.5 cm
- 5.0 Gy for 5 ft to 0.5 cm
- 7.5 Gy in 5 ft to VS
- Other

Brachytherapy. 2015.
PROSTATE BRACHYTHERAPY

TREATMENT OPTIONS

Modern Radiation Therapy

Brachytherapy

- Low Dose Rate
  - Permanent Seeds
- High Dose Rate
  - Virtual Seeds
- 9 weeks
  - Standard Fractionation
- 4-5 weeks
  - Hypofractionation
- 1.5 weeks
  - SBRT

External Beam
HIGHER DOSES OF RADIATION TO THE PROSTATE IMPROVE CHANCES OF PSA CONTROL

FIGURE 1 | Relationship between dose and 5-year freedom from PSA failure for intermediate-risk patients treated with EBRT [adapted from Fowler (28)].

Meier R. Front Oncol. 2015.

HOW HIGH DO WE NEED TO GO? BED 200?
HOW CAN YOU GET TO A BED OF 200?

LOCATION, LOCATION, LOCATION

- Brachy provides a solution to safely dose escalate while limiting dose to OARs
- How high can we safely go?
- How high do we need to go?
HDR PROSTATE PRESCRIPTION

- Monotherapy (Brachy alone, 13.5 Gy x 2)
  - Low
  - Favorable intermediate risk
- Combination (Brachy+EBRT, 15 Gy x 1 + 45 Gy)
  - Unfavorable intermediate risk
  - High risk
- Salvage (local failure after prior EBRT)
  - 11 Gy x 2

PQR FOR PROSTATE HDR
LOGISTICS OF BRACHYTHERAPY

- Done in the operating room
- Spinal/Sedation vs General
- ~1 hour
- LDR – all seeds placed in OR
- HDR – treatment given later that day, second treatment next day/week (for monotherapy)

TRUS GUIDED PLACEMENT OF CATHETERS

75

76
HDR BRACHYTHERAPY
ULTRASOUND VS CT BASED PLANNING

Ultrasound planning – 2 implants, 1-2 weeks apart
Treatment done when you wake up

CT based planning – 2 implants, 1-2 weeks apart
vs 1 implant w/ overnight stay and treat next day
Treatment not done when you wake up

HDR Brachytherapy

Bladder
Prostate
Urinary Catheter
Rectum
Template

Brachytherapy Catheters
CONCLUSIONS

• Brachytherapy is a versatile tool that can be helpful in many disease sites
• It’s most commonly used in breast, gyn, prostate, and skin cancers
• It provides conformal dose to targets while limiting dose to surrounding OARs
• Safe/effective planning requires teamwork between MD, physicist, dosimetrist and therapist
• Brachytherapy is fun “team sport”!!