HDR Intra-Cavitary Approaches to APBI: Basic Physics and Limitations

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Disclosure
Consultant for SenoRx Inc.
Learning Objectives

- To learn about the devices used for intracavitary APBI and their dosimetry
- To learn about planning and define treatment appropriateness based on NSABP B-39/RTOG 0413
- To learn about a number of relevant topics for intracavitary APBI: dose perturbation due to contrast and air, probabilistic aspects of planning and delivery, etc.
- To learn about Quality Assurance methods
- To learn about optimization methods
Outline

- Rationale for APBI
- Devices presentation
- NSABP B39/RTOG 0413
- Interesting topics
- Optimization
Why APBI?

- The underlying assumption is that the risk of ipsilateral breast cancer recurrence resides within proximity to the original tumor site.
- Accelerated partial-breast irradiation involves treating a limited volume of tissue, with an increased dose per fraction and a significantly decreased treatment time course.
Available methods

- Interstitial brachytherapy (LDR and HDR)
- *Intra-cavitary brachytherapy* (HDR)
- Intra-operative brachytherapy (HDR)
- Permanent breast seed implants (LDR)
- 3D conformal EBRT
Intra-cavitary devices

- Balloon based devices:
  - MammoSite
  - Contura

- Strut-based devices:
  - SAVI (Strut Adjusted Volume Implant)
  - Clear-Path
Balloon Catheter

‘MammoSite’

- MammoSite device (Proxima, Cytyc, Hologic)
- Inflatable Balloon Placed In Lumpectomy Cavity
- HDR brachytherapy 34 Gy in 10 fractions
- FDA clearance May 2002
- Since 2002, > 45,000 cases treated

Balloon based applicators
Contura, MammoSite (ML)
Strut devices

ClearPath™ Breast Brachytherapy

Hybrid Device: “Best of Both Worlds”

Patel ASTRO 2006

In development with North American Scientific, Inc 2006
Strut Adjusted Volume Implant Applicator
Iridium 192

- **Ir-192 is the most common source for Remote Afterloaders**
- **Disadvantage:** relative short half-life (at least when compared with Co-60 or Cs-137)
- **Advantage:** low average energy (~.38 Mev, with a range from 0.136 to 1.062MeV) so it is easily shielded requiring just 0.3cm Pb as a half value layer.
- **Advantage:** high specific activity (450Ci/g) allows the construction of high activity sources (10Ci) of small diameter (0.6-1.1 mm)
# Electronic Brachytherapy

## Axxent Electronic Brachytherapy System

<table>
<thead>
<tr>
<th>Axxent HDR X-ray Source 2.2 Specifications</th>
<th>Part Number</th>
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<tbody>
<tr>
<td>Axxent HDR X-ray Source</td>
<td>$7500</td>
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<tr>
<td>X-ray Tube Diameter</td>
<td>2.25 mm</td>
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<tr>
<td>Assembly Length</td>
<td>250 mm</td>
</tr>
<tr>
<td>Assembly Diameter</td>
<td>5.4 mm</td>
</tr>
<tr>
<td>X-ray Source Power</td>
<td>15 watts</td>
</tr>
<tr>
<td>Typical Treatment Time</td>
<td>10 min</td>
</tr>
<tr>
<td>Maximum Number of Treatments per X-ray Source</td>
<td>10</td>
</tr>
<tr>
<td>Source Includes</td>
<td></td>
</tr>
<tr>
<td>• Integral water cooling sheath</td>
<td></td>
</tr>
<tr>
<td>• Low-force high-voltage connector</td>
<td></td>
</tr>
<tr>
<td>• Flexible high-voltage cable</td>
<td></td>
</tr>
<tr>
<td>Nominal Dose Rate</td>
<td>0.6 Gy/min @ 3 cm in water</td>
</tr>
</tbody>
</table>
Review: three sources

Both the 169-Ytterbium source and the 192-Iridium source provide comparable coverage for the prescription dose (V100) and minimum dose to 90% of the target (D90).

The 169-Ytterbium source results in less volume receiving doses of 150% and 200% of the prescription. The 169-Ytterbium source also results in a greater homogeneity (DHI) and lower maximum dose.

The X-ray source performed worse in all categories.

The mean %V(90) was 99.6% vs. 99.0%, the mean %V(100) was 96.5% vs. 96.5%, the mean %V(150) was 41.8% vs. 59.4%, the mean %V(200) was 11.3% vs. 32.0% and the mean %V(300) was 0.4% vs. 6.7% for the IBB and KVB methods, respectively.

The IBB and KVB methods of PBI offer comparable target volume coverage; however, the KVB method is associated with an increased volume of breast tissue in the high-dose regions and a decreased dose to the adjacent normal tissues.

1. Dosimetric comparison of three radiation sources used in balloon-based breast brachytherapy John J. Munro, Ph.D. David C. Medich, Ph.D., Brachytherapy 6 (2007) 77-118
• The mass-energy absorption coefficient as a function of photon energy $E$ and atomic number $Z$, may be used to account for differences in absorbed dose between water and tissue. The ratio dips around 50keV due to slightly higher photoelectric cross section of tissue compared to water.

• Similarly, the mass-attenuation coefficient as a function of photon energy $E$ and atomic number $Z$ may approximate differences in radiation attenuation between water and tissue.

• Unlike the absorbed dose ratios, the larger mass density of tissue contributes to the increased attenuation. Further, increased attenuation by tissue below 50 keV is caused by the larger photoelectric effect cross section of tissue compared to water.

TG-43 vs. MC

(MammoSite) For the breast patient plan, TG-43 overestimates the target volume receiving the prescribed dose by 4% and the dose to the hottest 0.1 cm³ of the skin by 9% (Poon E, Verhaegen F. A CT-based analytical dose calculation method for HDR 192Ir brachytherapy. Med Phys. 2009 Sep;36(9):3982-94.)

(Multicath) On average, TG-43 overestimates the target coverage by 2% and the dose to the hottest 0.1 cm³ (D0.1 cc) of the skin by 5%. (Poon E, Verhaegen F. Development of a scatter correction technique and its application to HDR 192Ir multicatheter breast brachytherapy. Med Phys. 2009 Aug;36(8):3703-13.)

The introduction of deterministic Linear Boltzman Transport Equation based methods in the first commercial planning platform Acuros (Varian, Inc.) in brachytherapy
Elements of NSABP B39 / RTOG 0413 protocol

- Partial Breast Irradiation (PBI) By Multi-catheter Brachytherapy
- Partial Breast Irradiation (PBI) By Mammosite® Balloon Catheter
Target Volumes

- CTV = PTV = PTV_EVAL
- PTV_EVAL = excision cavity + uniform 15mm (10mm for MammoSite) except:
  - PTV_EVAL limited to 5mm from the skin surface
  - Chest wall and pectoralis muscles are excluded
Air inside balloon – small volume, no impact on target coverage

Planning target volume for evaluation (PTV_EVAL)
- equals planning target volume (PTV)
- equals clinical target volume (CTV)

1 cm

Contoured balloon surface

2 mm inside skin

Air outside balloon – pushes PTV beyond isodose coverage – must be contoured and the percent of PTV that it represents subtracted from the percent of PTV_EVAL covered by ≥90% of prescribed dose.

Excludes pectoralis muscles and chest wall.

Planning target volume for evaluation (PTV_EVAL)
- equals planning target volume (PTV)
- equals clinical target volume (CTV)

5 mm inside skin

Excision Cavity

1.5 cm

Excludes pectoralis muscles and chest wall.
Three models/sizes: 7, 9 and 11 struts available for loading.
SAVI -Strut-Adjusted Volume Implant brachytherapy applicator

Results: 3

1. Evaluation of three APBI techniques under NSABP B-39 guidelines.
   Scanderbeg D, Yashar C, White G, Rice R, Pawlicki T.
   PMID: 20160580 [PubMed - indexed for MEDLINE]
   Related citations

2. Initial clinical experience with the Strut-Adjusted Volume Implant brachytherapy applicator for accelerated partial breast irradiation.
   Yashar CM, Blair S, Wallace A, Scanderbeg D.
   PMID: 19744802 [PubMed - indexed for MEDLINE]
   Related citations

3. Clinical implementation of a new HDR brachytherapy device for partial breast irradiation.
   Scanderbeg DJ, Yashar C, Rice R, Pawlicki T.
   PMID: 18952310 [PubMed - indexed for MEDLINE]
   Related citations
"This breast brachytherapy device combines the ease of the single-entry device with the flexibility of IBT while still treating the minimal tissue necessary for APBI. "
DDVH shows a long ‘hot’ tail. Not only do we have tissue receiving 200%PD but also 300%PD and 400%PD.
courtesy of Rebecca Kitchen M.S., DABR, Radiation Oncology, Aurora BayCare Medical Center, Green Bay, WI
Interesting topics

- Dose perturbations due to contrast medium and air
- Probabilistic aspects of brachytherapy treatments
- The effect of patient inhomogeneities
- Dose to skin
- Chest wall dose
Dose perturbations due to contrast medium and air

The radio-opaque iodine-based contrast solution produces dose perturbation up to 6% (for the largest balloon diameter and contrast concentration, relative to a water-filled balloon).

The dose near the balloon surface may be increased by 0.5% per cm³ of air.

Limiting the contrast concentration to 10% would insure less than 3% reduction in the prescription dose, regardless of balloon diameter.

Dosimetric effects of an air cavity for the SAVITM partial breast irradiation applicator

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(Received 8 July 2009; revised 3 June 2010; accepted for publication 5 June 2010; published 12 July 2010)

Purpose: To investigate the dosimetric effect of the air inside the SAVITM partial breast irradiation device.

Methods: The authors have investigated how the air inside the SAVITM partial breast irradiation device changes the delivered dose from the homogeneously calculated dose. Measurements were made with the device filled with air and water to allow comparison to a homogenous dose calculation done by the treatment planning system. Measurements were made with an ion chamber, TLDs, and film. Monte Carlo (MC) simulations of the experiment were done using the EGSnrc suite. The MC model was validated by comparing the water-filled calculations to those from a commercial treatment planning system.

Results: The magnitude of the dosimetric effect depends on the size of the cavity, the arrangement of sources, and the relative dwell times. For a simple case using only the central catheter of the largest device, MC results indicate that the dose at the prescription point 1 cm away from the air-water boundary is about 9% higher than the homogeneous calculation. Independent measurements in a water phantom with a similar air cavity gave comparable results. MC simulation of a realistic multidwell position plan showed discrepancies of about 5% on average at the prescription point for the largest device.

Conclusions: The dosimetric effect of the air cavity is in the range of 3%–9%. Unless a heterogeneous dose calculation algorithm is used, users should be aware of the possibility of small treatment planning dose errors for this device and make modifications to the treatment delivery, if necessary. © 2010 American Association of Physicists in Medicine. [DOI: 10.1118/1.3457328]
Errors and uncertainty in delineation, planning and delivery for balloon PBI treatments

The most probable sources of systematic and random error contributions were identified and the impact on the accuracy of delivered dose studied. They include the effect of:

1. variation in CT resolution and
2. respiratory motion on the accuracy of balloon delineation,
3. contrast concentration on the accuracy of balloon delineation,
4. contouring variability on the accuracy of balloon and planning structure delineation,
5. the variability of applicator tip identification and applicator length,
6. dose matrix sampling on the reported DVH parameters and
7. source position uncertainty.
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</thead>
<tbody>
<tr>
<td>C1/Plan1</td>
<td>FTV</td>
<td>34.0</td>
<td>100.0</td>
<td>100.0 / 99.8</td>
<td>119.7</td>
<td>27.1</td>
<td>95.9</td>
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**C1/Plan1**

Dose = 33.96 Gy
Volume = 114.68 cm³
The effect of patient inhomogeneities

- Treatment planning system software featuring a full TG-43 dose calculation algorithm consider the patient geometry as a homogeneous water medium.
- The comparison of Monte Carlo results and treatment planning system calculations revealed that all percentage isodose contours greater than 60% of the prescribed dose are not affected by the finite breast dimensions or the presence of the lung.
- Treatment planning system calculations overestimate dose in the lung as well as lower isodose contours at points lying both close to the breast or lung surface and relatively away from the implant.

The effect of patient finite dimensions

Most treatment-planning systems currently in use for brachytherapy procedures use water-based dosimetry with no correction for heterogeneity. Therefore, these systems assume that full scatter exists regardless of the amount of tissue beyond the prescription line.

In fact, the resulting limited scatter could cause an **underdose** to be delivered along the prescription line.
Pre-treatment QA

- Balloon Diameter (ultrasound, fluoroscopy, CT)
- Rotation (for the devices that can potentially rotate)
- Catheter and transfer tube length
- Correct identification of treatment lumens and their assignment to the proper afterloader channels
Ultrasound Image of Contura

Central lumen Perpendicular on the Transducer’s Imaging plane
courtesy of Rebecca Kitchen M.S., DABR, Radiation Oncology, Aurora BayCare Medical Center, Green Bay, WI
Thank you.
On optimization

- Get to know (and understand) your optimizer.
  If optimization doesn’t create ‘optimal’ plans, something is wrong!
- Use of pseudo-structures
- Constraints (typically Dose-Volume)
- Experiment!
### Question 1

Which of the four devices presented do not involve the presence of a balloon?

<table>
<thead>
<tr>
<th>20%</th>
<th>MammoSite</th>
</tr>
</thead>
<tbody>
<tr>
<td>20%</td>
<td>MammoSite ML</td>
</tr>
<tr>
<td>20%</td>
<td>Contura</td>
</tr>
<tr>
<td>20%</td>
<td>SAVI</td>
</tr>
<tr>
<td>20%</td>
<td>Xoft electronic brachytherapy device</td>
</tr>
</tbody>
</table>
Answer

Q1 – 4

References


Question 2

The primary purpose of the balloon is:

- 20% to make the target reproducible
- 20% to keep the breast tissue away from the source
- 20% to compress the breast tissue
- 20% to stretch the breast tissue
- 20% to place between source and tissue an tissue ‘equivalent’ medium
Q2 – 2

References


Question 3

When TG43 is employed to compute dose for APBI, which device/source is likely to be more affected by the presence of inhomogeneities?

<table>
<thead>
<tr>
<th>20%</th>
<th>MammoSite/ Ir-192</th>
</tr>
</thead>
<tbody>
<tr>
<td>20%</td>
<td>MammoSite ML / Ir-192</td>
</tr>
<tr>
<td>20%</td>
<td>Contura / Ir-192</td>
</tr>
<tr>
<td>20%</td>
<td>SAVI / Ir-192</td>
</tr>
<tr>
<td>20%</td>
<td>Xoft electronic brachytherapy (eBx) balloon device/50kV xrays</td>
</tr>
</tbody>
</table>
References:

1. Dosimetric comparison of three radiation sources used in balloon-based breast brachytherapy
   John J. Munro, Ph.D. David C. Medich, Ph.D., Brachytherapy 6 (2007) 77-118

2. A dosimetric comparison of MammoSite high-dose-rate brachytherapy and Xoft Axxent electronic
   Brachytherapy. 2007 Apr-Jun;6(2):164-8