Intra-Operative Radiation Therapy using Mobile Linear Accelerators

Sam Beddar, Ph.D., FCCPM, FAAPM
Professor & Chief of Research

Department of Radiation Physics
The University of Texas MD Anderson Cancer Center
1905 – Carl Beck
History of IORT

- 1st report of IORT in 1907 by Carl Beck
- 1964 Abe in Japan
- 1st US IORT in 1975 @ Howard University
- 1st Mobile LINAC: Novac7 in Italy in 1997
- 1st Mobile LINAC Mobetron prototype in the US: UCSF in 1998
- 1st Commercial Mobetron installed @ University Hospitals of Cleveland in 1999
Before the mobile systems

- The tremendous logistics to transport the patient under anesthesia from the OR to radiation oncology deterred many centers from implementing the procedure.
- Many centers lost interest after only few cases.
Novac 7
Mobetron 2000
Commissioning – before & after
... It goes around corners
… to the OR floor

…it fits in elevators, but can’t walk up stairs yet
... in the OR

Control console outside the OR
Almost ready to treat
Soft Docking – Laser Alignment System
Treatment Delivery
Multidisciplinary: Roles & Team Work

- Anesthesia
- Operative Nursing
- Surgeon
- Medical Physicist
- Radiation Oncologist
- IORT
Advantages of IORT
Advantages of IORT

- Provides a large dose of radiation to the tumor/tumor bed at the time of surgery, while normal tissues can be displaced from the radiation field.
- Potentially decreases side effects and complications of radiation therapy.
- Shortens overall treatment time for the patients by decreasing the number of visits to the Radiation Oncology Department.
- Social niche (breast cancer):
  - poor countries, with no access to breast conservation - an alternative.
  - rich countries, where patients can’t fit RT treatment into their schedules.
Advantages of IORT

Depth of penetration in tissue or muscle

- IOEBRT vs IOHDR
- 6 MeV
- 9 MeV
- 12 MeV

3 CM

100%
50%
Machine Characteristics

- Electron energies: 4, 6, 9 and 12 MeV with dose rates up to 10Gy/min
- Flat and beveled electron applicators (3.0 to 10.0 cm, 0.5 cm increments)
- Plastic Boluses (0.5 or 1.0 cm)
- Soft-docking system
- 50 cm nominal SSD, non-isocentric
- 6 degrees of freedom (3 transl., 3 rot.)
- Beam stopper tracks the beam (self-shielded)
- No need for shielding in the OR
- Plugs into normal 3-phase electrical outlet / single-phase input

Wootton et. al., 2016
Why No Shielding Requirements?

• Electron Beam Only—Low beam current greatly reduces radiation leakage.

• No Bending Magnet – The most significant source of leakage in a conventional accelerator is eliminated.

• X-ray Contamination – Extremely Low!

A self-shielded accelerator

Fig. 2. uGy/1000 Monitor Units at 2 meters in the Y Plane

Mills et. al., 2001
References – Mobile Systems

Disclaimer

I am only providing these additional slides for additional information and educational purposes to complement my personnel presentation and experience using the Mobetron 1000. The slides below were obtained from IntraOp Medical to show the new version of the Mobetron: Mobetron 2000.

The author has no direct affiliation with Intraop Medical, Inc. and received no financial support for the research reported in his work in the past/present or for giving this invited presentation.

The author thanks Derek Descioli, VP Global Sales. IntraOp and Dan Goer, Co-Founder of IntraOp in 1993 and serving currently as its Chief Scientist.
IntraOp Mobetron Treatment Applications
## Treatment Application Characteristics

<table>
<thead>
<tr>
<th>Tumor</th>
<th>Energy [MeV]</th>
<th>Applicator diameter [cm]</th>
<th>Bevel [deg]</th>
<th>½ cm sized applicators</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>6</td>
<td>9</td>
<td>12</td>
<td>0</td>
</tr>
<tr>
<td>Breast</td>
<td>26%</td>
<td>48%</td>
<td>24%</td>
<td>53%</td>
</tr>
<tr>
<td>Colorectal</td>
<td>35%</td>
<td>50%</td>
<td>10%</td>
<td>8%</td>
</tr>
<tr>
<td>Pancreas</td>
<td>24%</td>
<td>26%</td>
<td>49%</td>
<td>73%</td>
</tr>
<tr>
<td>Sarcoma-Extremity</td>
<td>45%</td>
<td>46%</td>
<td>8%</td>
<td>39%</td>
</tr>
<tr>
<td>Sarcoma-RPS</td>
<td>22%</td>
<td>58%</td>
<td>19%</td>
<td>34%</td>
</tr>
</tbody>
</table>

Source: IntraOp Mobetron User Database
IntraOp Mobetron Output Stability
Mobetron Output Variation for Various Energies

Source: Beddar, et al. 2005
### Mobetron Long Term Stability

<table>
<thead>
<tr>
<th>Electron Energy</th>
<th>4 MeV</th>
<th>6 MeV</th>
<th>9 MeV</th>
<th>12 MeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commissioning 1999</td>
<td>0.999</td>
<td>0.997</td>
<td>0.993</td>
<td>1.001</td>
</tr>
<tr>
<td>Annual Calibration 2000</td>
<td>0.987</td>
<td>0.993</td>
<td>1.004</td>
<td>1.010</td>
</tr>
<tr>
<td>Percent Change (%)</td>
<td>-1.2%</td>
<td>-0.4%</td>
<td>+1.1%</td>
<td>+0.9%</td>
</tr>
</tbody>
</table>

Source: Beddar, Et al. 2005
Mobetron Energy Ratio Variation

Equivalent PDD Shift

<table>
<thead>
<tr>
<th>Energy (MeV)</th>
<th>PDD Shift (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>0.6</td>
</tr>
<tr>
<td>6</td>
<td>0.8</td>
</tr>
<tr>
<td>9</td>
<td>0.8</td>
</tr>
<tr>
<td>12</td>
<td>0.4</td>
</tr>
</tbody>
</table>

Source: Beddar, et al. 2005
Technical and Clinical Review of Mobetron Usage
Mobetron Treatments Characteristics

► Worldwide, 56% of Mobetron treatments were for breast cancer (83% in Europe, 20% in the U.S, and 33% in Asia).

► For the non-breast data main sites were: Colorectal (21%), Pancreas (15%), Extremity Sarcomas (22%) and RPS (8%).
Breast data characteristics

- 71% of breast patients were treated as a boost (75% EU, 72% U.S., 16% Asia).
- 29% of boost treatments followed by 3 weeks EBRT.
- 48% were treated at 9 MeV; 26% at 6 MeV; and 24% at 12 MeV (2% @ 4 MeV).
Breast data characteristics (continued)

- For the breast data received:
  - 84% of patients were treated with FS between 4-6 cm.
  - 35% of patients were treated with a ½ cm sized applicator.
  - 3% of patients were treated with a FS > 7 cm.
ISIORT Breast Treatments Characteristics

► 42 Collaborating Centers
► 8,075 Breast cancer patients
  ▶ Median age 61 years (16 – 90)
  ▶ 81.8% T1 and 16.1% T2
  ▶ 96.5% Ductal carcinoma; 3.5% Lobular
  ▶ 52.2% Surgery + IORT
  ▶ 47.8% Surgery + IORT + EBRT
  ▶ CT in 13.2% of cases

Beam energy

9 MeV 25%
8 MeV 12%
7 MeV 12%
6 MeV 24%
50 kV 8%
4 MeV 6%
12 MeV 6%
10 MeV 7%
APBI Single Fraction Treatment Clinical Results
## Single Fraction Clinical Results

<table>
<thead>
<tr>
<th>Reference</th>
<th>Median FU (yrs)</th>
<th>Total # pts</th>
<th># LR</th>
<th>LR (%)</th>
<th># pts ASTRO Suitable</th>
<th>#LR</th>
<th>LR (%)</th>
<th># pts ESTRO Good</th>
<th>#LR</th>
<th>LR (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ELIOT (1)</td>
<td>5.8</td>
<td>585</td>
<td>34</td>
<td>5.8%</td>
<td>135</td>
<td>2</td>
<td>1.5%</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>ELIOT Out Trial</td>
<td>3.5*</td>
<td>1822</td>
<td>75</td>
<td>4.1%</td>
<td>294</td>
<td>3</td>
<td>1.0%</td>
<td>573</td>
<td>7</td>
<td>1.2%</td>
</tr>
<tr>
<td>U. of Verona (4,5)</td>
<td>5</td>
<td>226</td>
<td>4</td>
<td>1.8%</td>
<td>128</td>
<td>1</td>
<td>0.8%</td>
<td>160</td>
<td>3</td>
<td>1.9%</td>
</tr>
<tr>
<td>Brussels (6)</td>
<td>2</td>
<td>204</td>
<td>1</td>
<td>0.5%</td>
<td>87</td>
<td>1</td>
<td>1.1%</td>
<td>151</td>
<td>1</td>
<td>0.7%</td>
</tr>
<tr>
<td>Japan (7)</td>
<td>6</td>
<td>32</td>
<td>0</td>
<td>0%</td>
<td>16</td>
<td>0</td>
<td>0%</td>
<td>28</td>
<td>0</td>
<td>0%</td>
</tr>
<tr>
<td>Brazil (8)</td>
<td>4.3</td>
<td>152</td>
<td>5</td>
<td>3.2%</td>
<td>48</td>
<td>0</td>
<td>0%</td>
<td>92</td>
<td>2</td>
<td>1.9%</td>
</tr>
<tr>
<td>Naples (9)</td>
<td>4</td>
<td>13</td>
<td>0</td>
<td>0%</td>
<td>7</td>
<td>0</td>
<td>0%</td>
<td>13</td>
<td>0</td>
<td>0%</td>
</tr>
<tr>
<td>China (11)</td>
<td>4.3</td>
<td>36</td>
<td>2</td>
<td>5.6%</td>
<td>2</td>
<td>0</td>
<td>0%</td>
<td>6</td>
<td>0</td>
<td>0%</td>
</tr>
<tr>
<td>Stanford (10)</td>
<td>6.8</td>
<td>64</td>
<td>1</td>
<td>1.6%</td>
<td>-</td>
<td>0</td>
<td>0%</td>
<td>-</td>
<td>0</td>
<td>0%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>3134</strong></td>
<td><strong>122</strong></td>
<td><strong>717</strong></td>
<td><strong>7</strong></td>
<td><strong>1023</strong></td>
<td><strong>13</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: Horst et al., Presented at 2016 ASCO Annual Meeting

5 yr LR of <2% for Low Risk Patients
Updated ASTRO APBI Guidelines Affirm the use of Electron IORT

- 2016 ASTRO APBI Consensus Guidelines update removes experimental status for electron IORT in suitable patients
- Citing Evidence from Multivariate analysis on randomized trial with median follow up of 5.8 years
- More than 3,000 patients receiving single treatment electron IORT have been studied in the literature
- Electron IORT is the only single treatment option recognized by the updated ASTRO guidelines

**ASTRO Suitable Criteria**

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>AGE</td>
<td>50 years or older</td>
</tr>
<tr>
<td>SIZE</td>
<td>≤2 cm</td>
</tr>
<tr>
<td>NODAL STATUS</td>
<td>pN0</td>
</tr>
<tr>
<td>HISTOLOGY</td>
<td>IDC/Favorable</td>
</tr>
<tr>
<td>MARGINS</td>
<td>Negative (≥2mm)</td>
</tr>
<tr>
<td>ESTROGEN RECEPTOR</td>
<td>Positive</td>
</tr>
<tr>
<td>LVI</td>
<td>Negative</td>
</tr>
<tr>
<td>DCIS</td>
<td>Low to intermediate ≤ 2.5 cm</td>
</tr>
<tr>
<td>DCIS MARGIN</td>
<td>Negative (≥ 3 mm)</td>
</tr>
<tr>
<td>SYSTEMIC THERAPY</td>
<td>No neoadjuvant</td>
</tr>
<tr>
<td>GRADE</td>
<td>Any</td>
</tr>
</tbody>
</table>