Delivery Systems II - Characteristics of Dedicated and Specialized Systems

Alonso N. Gutierrez, Ph.D.
Associate Professor
University of Texas Health Science Center San Antonio (UTHSCSA)
gutierrezan@uthscsa.edu
Disclosures

- Ownership: VeriDos Solutions, LLC
Learning Objectives

• Understand the requirements for a dedicated SRT delivery system
• Understand the features of the dedicated and specialized SRT linacs: Novalis platforms, CyberKnife, and Vero
• Understand the features and design of newly emerging dedicated SRT systems: EDGE and ViewRay.
Outline of Presentation

• Machine characteristics for SRT
• Novalis, Tx, STx Platform
• CyberKnife Platform
• Vero Platform
• Emerging technologies
Ideal Delivery Equipment

- **Accuracy/Stability**
  - Mechanical (≤ 1.0mm)
  - Dosimetric (≤ 1.0%)
  - Imaging (≤ 1.0mm)

- **Precision via fine apertures**
  - microMLC (≤ 5.0mm leaf)
  - Cones
  - IRIS collimator

- **Delivery techniques**
  - Inverse planning - IMRT/VMAT
  - Arc-based

AAPM TG 101 2010
Ideal Delivery Equipment

• Image guidance
  – Accurate localization (≤ 1.0mm)
  – Volumetric image information
  – Real-time imaging (4D)

• Delivery efficiency
  – High dose rate (≥800 MU/min)
  – Arc/VMAT delivery

• Throughput
  – Established, integrated workflow
Evaluating System Performance

- Specialized SBRT/ SRS phantoms
  - End-to-end testing **crucial**
    - Spatial accuracy (hidden target)
    - Dosimetric accuracy
  - *E2E needs to incorporate imaging*
The end-to-end localization assessment, “hidden target test,” using SRS frame-based and/or IGRT system is:

<table>
<thead>
<tr>
<th>Percentage</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>94%</td>
<td>≤ 1.0mm</td>
</tr>
<tr>
<td>1%</td>
<td>≤ 1.5mm</td>
</tr>
<tr>
<td>5%</td>
<td>≤ 2.0mm</td>
</tr>
<tr>
<td>1%</td>
<td>≤ 2.5mm</td>
</tr>
<tr>
<td>0%</td>
<td>≤ 3.0mm</td>
</tr>
</tbody>
</table>
The end-to-end localization assessment, “hidden target test,” using SRS frame-based and/or IGRT system is:

1. $\leq 1.0\text{mm}$
2. $\leq 1.5\text{mm}$
3. $\leq 2.0\text{mm}$
4. $\leq 2.5\text{mm}$
5. $\leq 3.0\text{mm}$

Answer: 1. $\leq 1.0\text{mm}$

Universal Functionality

VersaHD™

TomoHDA™

TrueBeam™ STx
Dedicated SRT Systems

Vero™

CyberKnife M6™

EDGE™

GK Perfexion™
Despite the nice equipment.....

Don’t forget the fundamentals!
Novalis “Classic” Platform

- Original platform (Varian 600C)
- Collimators
  - Cones
  - mMLC (3mm)
- ExacTrac imaging
- System accuracy
  - 0.32±0.42 mm*
- Delivery techniques
  - IMRT
  - Dynamic conformal arcs

Novalis Tx Platform

- Trilogy platform
- Collimation
  - HD120 MLC (2.5mm)
  - Cones
- ExacTrac & OBI
- 6DOF couch
- Dose rate – 1000MU/min
- Delivery Capabilities
  - IMRT
  - VMAT
  - DCA

Commissioning - Novalis Tx

TrueBeam™ STx Platform

- TrueBeam platform
- Collimation
  - HD120 MLC (2.5mm)
  - Cones
- ExacTrac & OBI
- Accuracy
  - G/C/Col: 0.46-0.68mm*
- Delivery capabilities
  - Similar to NTx
- FFF Mode
  - 6XFFF: 1400 MU/min
  - 10XFFF: 2400 MU/min

“Overall, excellent agreement was observed in TrueBeam commissioning data.”
# Novalis - Imaging Hardware

TABLE 1. Technical specifications of imaging detectors mounted on NTX.

<table>
<thead>
<tr>
<th></th>
<th>MV Imager (EPID)</th>
<th>OBI kV imager</th>
<th>ExacTrac X-ray (ETX)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>PortalVision aSi1000</td>
<td>Paxscan 4030CB</td>
<td>XRD 840 AN</td>
</tr>
<tr>
<td>Type</td>
<td>aSi</td>
<td>aSi</td>
<td>aSi</td>
</tr>
<tr>
<td>Pixel Matrix (Pixel Pitch)</td>
<td>1024×768, (0.392 mm)</td>
<td>2048×1536, (0.194 mm)</td>
<td>512×512, (0.398 mm)</td>
</tr>
<tr>
<td>Active imaging area</td>
<td>400 mm (h)×300 mm²</td>
<td>397 mm (h)×298 mm²</td>
<td>204×204 mm²</td>
</tr>
<tr>
<td>Energy range</td>
<td>4–25 MV</td>
<td>40–150 kVp</td>
<td>40–225 kVp</td>
</tr>
<tr>
<td>Frame rate (Frames/sec)</td>
<td>1–10 fps</td>
<td>7.5 fps (1×1 bin mode)</td>
<td>30 fps (2×2 bin mode)</td>
</tr>
</tbody>
</table>

Novalis - Imaging

- ExacTrac System
  - Two kV x-rays
  - Two aSi flat panel detectors
  - Optical infrared tracking system
  - 6D robotic carbon fiber couch
- Geometrical accuracy
  - Isocenter accuracy: 0.35mm*
  - 6D positional accuracy: 0.07 ± 0.22mm*
- Enables beam gating

*Takakura T et al. PMB. 2010.
ExacTrac Gating

• Initial clinical use: Lung/markers
  – X-ray & Infrared marker-based
  – Model based on marker/infrared correlation

• Localization accuracy
  – 1.7mm*
  – CT slice thickness
  – Coil size dependent

Table 2. Ion chamber readings for 300 monitor units delivered at various gating windows (10%, 20%, and 40%) for two different dose rates (480 MU/min and 800 MU/min); all ion chamber readings are normalized to the reading obtained in non gated mode.

<table>
<thead>
<tr>
<th>Gating window</th>
<th>480 MU/min</th>
<th>800 MU/min</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Reading</td>
<td>Time (min)</td>
</tr>
<tr>
<td>10%</td>
<td>1.004</td>
<td>8.94</td>
</tr>
<tr>
<td>20%</td>
<td>1.001</td>
<td>2.11</td>
</tr>
<tr>
<td>40%</td>
<td>1.005</td>
<td>1.72</td>
</tr>
<tr>
<td>Non gated</td>
<td>1.000</td>
<td>0.63</td>
</tr>
</tbody>
</table>

Abbreviation: MU = monitor units.

• Structures on pre-treatment fluoroscopic trace
• Gating: x-ray-based
• Triggered Imaging
  – MU, Gantry position, Time, Respiratory gates
• 2D/3D Match
ExacTrac vs. kV CBCT

- Cranial lesions
- General agreement localization accuracy – NS
- Strict QA congruence b/w mechanical and imaging isocenters

Ma J, et al. Rad Oncol. 93. 2009

Table 2
Residual setup errors and differences between ExacTrac X-ray 6D and CBCT for the phantom (n = 16).

<table>
<thead>
<tr>
<th>Displacement direction</th>
<th>Residual error for ExacTrac X-ray 6D (RMS, SD)</th>
<th>Residual error for online 3D CBCT (RMS, SD)</th>
<th>Residual error for offline 6D CBCT (RMS, SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Translation (mm)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LR</td>
<td>0.17, 0.17</td>
<td>0.35, 0.33</td>
<td>0.40, 0.40</td>
</tr>
<tr>
<td>SI</td>
<td>0.20, 0.19</td>
<td>0.43, 0.43</td>
<td>0.46, 0.45</td>
</tr>
<tr>
<td>AP</td>
<td>0.30, 0.29</td>
<td>0.50, 0.48</td>
<td>0.52, 0.49</td>
</tr>
<tr>
<td>Rotation (degree)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pitch</td>
<td>0.18, 0.17</td>
<td>0.12, 0.12</td>
<td>0.02, 0.02</td>
</tr>
<tr>
<td>Roll</td>
<td>0.22, 0.21</td>
<td>0.13, 0.12</td>
<td>0.03, 0.03</td>
</tr>
<tr>
<td>Yaw</td>
<td>0.19, 0.12</td>
<td>0.17, 0.06</td>
<td>0.15, 0.15</td>
</tr>
</tbody>
</table>

ExacTrac X-ray 6D vs. online 3D CBCT

<table>
<thead>
<tr>
<th>Difference</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.26, 0.25</td>
<td>0.184</td>
</tr>
<tr>
<td>0.34, 0.34</td>
<td>0.776</td>
</tr>
<tr>
<td>0.39, 0.38</td>
<td>0.493</td>
</tr>
</tbody>
</table>

ExacTrac X-ray 6D vs. offline 6D CBCT

<table>
<thead>
<tr>
<th>Difference</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.29, 0.29</td>
<td>0.214</td>
</tr>
<tr>
<td>0.32, 0.31</td>
<td>0.225</td>
</tr>
<tr>
<td>0.38, 0.36</td>
<td>0.887</td>
</tr>
</tbody>
</table>

Abbreviations: 6D, 6 degree-of-freedom; CBCT, cone-beam computed tomography; RMS, root-mean-square; SD, standard deviation; LR, left-right; SI, superior-inferior; AP, anterior-posterior; Pitch, rotation around LR direction; Roll, rotation around SI direction; Yaw, rotation around AP direction; n, number of scans.

* The RMS error was calculated by taking the square root of the “sum of the squares divided by the number of scans.”
Because modern day stereotactic system depend heavily on imaging for accurate localization (i.e. establish stereotactic space), the recommended frequency and tolerance to verify mechanical and imaging isocenter coordinate coincidence for SRT systems are:

- 3% 1. Daily & ≤ 0.5mm
- 5% 2. Daily & ≤ 0.75mm
- 84% 3. Daily & ≤ 1.0mm
- 1% 4. Monthly & ≤ 0.5mm
- 6% 5. Monthly & ≤ 1.0mm
Because modern day stereotactic system depend heavily on imaging for accurate localization (i.e. establish stereotactic space), the recommended frequency and tolerance to verify mechanical and imaging isocenter coordinate coincidence for SRT systems are:

1. Daily & ≤ 0.5mm
2. Daily & ≤ 0.75mm
3. Daily & ≤ 1.0mm
4. Monthly & ≤ 0.5mm
5. Monthly & ≤ 1.0mm

Answer: 3. Daily & ≤ 1.0mm

Delivery Techniques

- Circular Arc
- Conformal Beam
- Dynamic Conformal Arc
- IMRT – SS/SW
- HybridArc
VMAT Techniques - RapidArc
VMAT vs. Fix Field?

- n=12 prostate cx
- VMAT, SS-IMRT, HT
- Results
  - VMAT & SS/IMRT comparable dosimetry
  - VMAT faster delivery efficiency
  - Tx time: 2.6±0.5min vs. 3.8±0.3min

Fig. 1. Axial, coronal, and sagittal isodose distributions by VMAT (upper panel), step-and-shoot IMRT (middle panel), and HT (lower panel) of one representative patient were shown.

VMAT vs. Fix Field - Spine SBRT

- n=10 spine SBRT
- Novalis Tx w/HD120MLC
- RapidArc
- Results
  - 2 arcs better than 1 arc
  - VMAT comparable TC
  - 2 arcs comparable OAR sparing (IMRT)
  - Tx time: 15.8 → 8.0min

Figure 1: (top) AP DRR of the location of the three lesions. The lesions are identified as follows: Location 1 – red, Location 2 – green, and Location 3 – yellow. (bottom) Right LAT DRR of the location of the three lesions.

Table 1: Statistical analysis of target coverage for fixed-field and VMAT plans. Statistics normalized to fixed-field IMRT (i.e. VMAT/IMRT).

<table>
<thead>
<tr>
<th>Location</th>
<th>CN</th>
<th>HI</th>
<th>R$_{95}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location 1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Large PTV (4.15 cm.)</td>
<td>0.87</td>
<td>0.97</td>
<td>1.29</td>
</tr>
<tr>
<td>Medium PTV (3.38 cm.)</td>
<td>0.91</td>
<td>1.00</td>
<td>1.20</td>
</tr>
<tr>
<td>Small PTV (2.03 cm.)</td>
<td>0.85</td>
<td>0.96</td>
<td>1.11</td>
</tr>
<tr>
<td>Location 2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Large PTV (4.74 cm.)</td>
<td>0.98</td>
<td>1.11</td>
<td>1.05</td>
</tr>
<tr>
<td>Medium PTV (3.50 cm.)</td>
<td>1.03</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Small PTV (1.98 cm.)</td>
<td>1.07</td>
<td>1.00</td>
<td>0.93</td>
</tr>
<tr>
<td>Location 3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Large PTV (4.68 cm.)</td>
<td>0.98</td>
<td>0.79</td>
<td>1.14</td>
</tr>
<tr>
<td>Medium PTV (3.24 cm.)</td>
<td>0.98</td>
<td>0.84</td>
<td>1.16</td>
</tr>
<tr>
<td>Small PTV (2.24 cm.)</td>
<td>1.01</td>
<td>1.04</td>
<td>1.01</td>
</tr>
</tbody>
</table>

Table 2: Statistics for normal liver tissue for fixed-field IMRT and VMAT plans. Statistics normalized to fixed-field IMRT (i.e. VMAT/IMRT).

<table>
<thead>
<tr>
<th>Location</th>
<th>D$_{mean}$</th>
<th>V$_{80%}$</th>
<th>V$_{20%}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location 1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Large PTV (4.15 cm.)</td>
<td>1.4</td>
<td>1.27</td>
<td>1.15</td>
</tr>
<tr>
<td>Medium PTV (3.38 cm.)</td>
<td>1.4</td>
<td>1.22</td>
<td>0.98</td>
</tr>
<tr>
<td>Small PTV (2.03 cm.)</td>
<td>1.3</td>
<td>1.19</td>
<td>0.87</td>
</tr>
<tr>
<td>Location 2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Large PTV (4.74 cm.)</td>
<td>0.9</td>
<td>0.92</td>
<td>0.93</td>
</tr>
<tr>
<td>Medium PTV (3.50 cm.)</td>
<td>0.9</td>
<td>0.91</td>
<td>0.86</td>
</tr>
<tr>
<td>Small PTV (1.98 cm.)</td>
<td>1.0</td>
<td>0.89</td>
<td>0.93</td>
</tr>
<tr>
<td>Location 3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Large PTV (4.68 cm.)</td>
<td>1.3</td>
<td>1.04</td>
<td>1.47</td>
</tr>
<tr>
<td>Medium PTV (3.24 cm.)</td>
<td>1.4</td>
<td>1.12</td>
<td>1.45</td>
</tr>
<tr>
<td>Small PTV (2.24 cm.)</td>
<td>1.3</td>
<td>0.96</td>
<td>1.24</td>
</tr>
</tbody>
</table>

Mueller B et al. Med Dosimetry. 2011
VMAT - SRT Various Sites

Pancreas
- SBRT RapidArc®: 2 arcs
- 9 Gy x 5 fractions
- 10X High Intensity Mode
- < 2.5 minutes beam-on time

Non-small Cell Lung
- RapidArc®: 2 partial arcs
- 12 Gy x 4 fractions
- 10X High Intensity Mode
- < 2.5 minutes beam-on time

Courtesy: Varian Medical
VMAT SRS - Multiple Mets

Plan quality and treatment planning technique for single isocenter cranial radiosurgery with volumetric modulated arc therapy

Grant M. Clark MD\textsuperscript{a}, Richard A. Popple PhD\textsuperscript{a}, Brendan M. Prendergast MD\textsuperscript{a}, Sharon A. Spencer MD\textsuperscript{a}, Evan M. Thomas MS\textsuperscript{a}, John G. Stewart MD\textsuperscript{a,}, Barton L. Guthrie MD\textsuperscript{b}, James M. Markert MD\textsuperscript{b}, John B. Fiveash MD\textsuperscript{a,*}

\textsuperscript{a}Department of Radiation Oncology, University of Alabama at Birmingham, Comprehensive Cancer Center, Birmingham, Alabama
\textsuperscript{b}Department of Neurosurgery, University of Alabama at Birmingham, Birmingham, Alabama

**FFF: SRT Implications**

- **6XFFF**
  - DR: 1400 MU/min
  - $PDD_{10}: 63.3\% v. 66.2\%$
- **10XFFF**
  - DR: 2400 MU/min
  - $PDD_{10}: 71.0\% v. 73.5\%$
- **Limitations**
  - Leaf speed
  - Gantry speed

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Flattening filter-free linac improves treatment delivery efficiency in stereotactic body radiation therapy

Brendan M. Prendergast,1 John B. Fiveash,1a Richard A. Popple,1 Grant M. Clark,1 Evan M. Thomas,1 Douglas J. Minnich,2 Rojyom Jacob,1 Sharon A. Spencer,1 James A. Bonner,1 Michael C. Dobelbower1

<table>
<thead>
<tr>
<th>Time Component</th>
<th>FFF (minutes)</th>
<th>Conventional (minutes)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>BOT</td>
<td>2.3±0.8</td>
<td>5.6±3.0</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>TtT</td>
<td>11.5±6.3</td>
<td>32.9±14.7</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Tt</td>
<td>21.1±8.7</td>
<td>40.8±17.6</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>IGT</td>
<td>9.6±2.7</td>
<td>13.9±5.9</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>IFDT</td>
<td>9.2±5.8</td>
<td>27.3±13.2</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>CDR</td>
<td>1890±478</td>
<td>584±46</td>
<td>&lt;0.01</td>
</tr>
</tbody>
</table>

Note: Mean time ± standard deviation (in minutes) of 5 treatment time components compared between FFF and conventional linac delivery. All tested time components were significantly shorter with FFF delivery. CDR (measured in MU/min) is significantly higher for FFF treatments.

BOT = beam on time; TtT = treatment time; IT = immobilization time; IGT = image guidance time; IFDT = intrafraction downtime; CDR = clinical dose rate; FFF = flattening filter-free; MU/min = monitor units per minute.
Flattening filter-free linac improves treatment delivery efficiency in stereotactic body radiation therapy

Brendan M. Prendergast, John B. Fiveash, Richard A. Popple, Grant M. Clark, Evan M. Thomas, Douglas J. Minnich, Rojymon Jacob, Sharon A. Spencer, James A. Bonner, Michael C. Dobelbower

Table 3. Univariate analysis of treatment time.

<table>
<thead>
<tr>
<th>Factor</th>
<th>Impact on TTX</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>FFF treatment</td>
<td>decreased</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>VMAT</td>
<td>decreased</td>
<td>0.02</td>
</tr>
<tr>
<td>IMRT</td>
<td>none</td>
<td>NS</td>
</tr>
<tr>
<td>Respiratory gating</td>
<td>increased</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>IF imaging</td>
<td></td>
<td></td>
</tr>
<tr>
<td>X-ray</td>
<td>none</td>
<td>NS</td>
</tr>
<tr>
<td>Conc-beam CT</td>
<td>increased</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>MU &gt; 3000</td>
<td>none</td>
<td>0.06</td>
</tr>
</tbody>
</table>

Note: Six factors tested for association with treatment time by univariate analysis. Use of FFF mode and VMAT were associated with shorter TTX, meanwhile, respiratory gating and intrafraction CT were associated with longer TTX. Use of IMRT, intrafraction X-ray, and larger numbers of MUs had no significant effect on TTX. FFF = flattening filter-free; VMAT = volumetric-modulated arc therapy; IMRT = intensity-modulated radiation therapy; CT = computed tomography; MU = monitor unit.
Which of the following is the key advantage of flattening filter free (FFF) mode in stereotactic deliveries with SRT machines:

0% 1. Lower effective beam energy
1% 2. Improved prescription dose conformity
3% 3. Faster dose fall-off
96% 4. Higher dose rate
0% 5. Improved normal tissue sparing
Which of the following is the key advantage of flattening filter free (FFF) mode in stereotactic deliveries with SRT machines:

1. Lower effective beam energy
2. Improved prescription dose conformity
3. Faster dose fall-off
4. Higher dose rate
5. Improved normal tissue sparing

Answer: 4. Higher dose rate

For stereotactic radiotherapy deliveries, the combined use of volumetric modulated arc therapy (VMAT) and flattening filter free (FFF) mode available with novel commercial linear accelerators has been shown to decrease treatment delivery time by approximately:

1. 15%
2. 30%
3. 55%
4. 70%
5. 90%
For stereotactic radiotherapy deliveries, the combined use of volumetric modulated arc therapy (VMAT) and flattening filter free (FFF) mode available with novel commercial linear accelerators has been shown to decrease treatment delivery time by approximately:

1. 15%
2. 30%
3. 55%
4. 70%
5. 90%

Answer: 4. 70%

CyberKnife Platform

- Robotic SRT system
- 6MV LINAC – 6DOF
- kV planar imaging
- All-time, real-time tracking
- Collimation
  - Cone
  - IRIS
  - MLC (M6)
- Accuracy
  - 0.29 +/- 0.10 mm*
- Dose rate
  - 1000MU/min

CyberKnife Evolution
CyberKnife - Imaging

- 2 diagnostic x-ray sources and flat panel detectors
- provides a stereotactic frame of reference
- enables to track, detect and correct for patient and target motion
- Imaging center is the reference point for image guidance and treatment planning

Courtesy: Dilini Pinnaduwage
- Real-time, live images are compared against DRRs generated from planning CT
- Robot adjusts position based on this comparison during treatment

Courtesy: Dilini Pinnaduwage
CyberKnife Tracking

- Four different tracking algorithms:
  - 6D Skull: brain, head and neck
  - Fiducial: soft tissue, prostate
  - Xsight Spine (XST): spine (prone or supine), lung
  - Xsight Lung (XLT): fiducial-less lung tracking

- Synchrony Respiratory Motion Tracking
  - Combined with Fiducial, lung or spine prone
  - It is used for lung, liver, pancreas and spine in prone position

Courtesy: Martina Descovich
Synchrony – 4D Tracking

- Correlation model between fiducial or tumor and surface LEDs
- Tracks on model using LEDs
- Verifies target position with x-ray imaging (~1 image/min)

CyberKnife Collimation
CyberKnife Collimation - MLC

- InCise MLC
  - 41 leaf pairs
  - 2.5mm @ 80cm
  - FS: 12x10cm²
- InCise vs. IRIS*
  - Decrease 38±10% MU
- Treatment time reduction
  - 30-45min to 15-20mins

CyberKnife Delivery Techniques

- Non-isocentric beam delivery
- Nominal SAD 80cm
- Site-specific, predefined beam node arrangement/templates
- Multiple beams/node (~150 beams)
- No “true” posterior beams
- RayTracing / MC-based dose algorithms
### SRS to SBRT to R-IMRT

- **1999**: SRS
  - Brain
  - Spine
  - Upper Spine

- **2001**: Spine
  - Prostate

- **2003**: Spine
  - Lung
  - Pancreas
  - Spine

- **2006**: Spine
  - H&N

- **2007**: Spine
  - Synchrony
  - Lung

- **2008**: Spine
  - Liver

- **2010**: Standard Fractions
  - Large Fields

- **2013**: Large Fields
  - MLC

---

**Total Patients Treated**

- **1999**: 30
- **2014**: ~100,000

---

*Courtesy: Martina Descovich*
CyberKnife Center Munich

- SRT sites
  - Spine
  - Lung
  - Pancreas
  - Prostate
  - Liver

- Potential for more sites w MLC

Vero Platform

- Gimbaled x-ray head
- 6MV photons
- Patient stationary (6DOF)
- Imaging (kV/MV)
- Dynamic tracking
- Collimation
  - MLC
- DR: 500 MU/min
Original System

- Mechanical design, precision
- Electronic design
- Large scale projects

MITSUBISHI HEAVY INDUSTRIES, LTD.

BRAINLAB

- Software development
- Precision SRS / SRT
- Treatment Planning
- Patient Positioning
Vero - Technical Specs

- **Energy**: 6 MV Photons
- **Dose rate**: Variable, max. 500 cGy/min
- **Isocenter accuracy**: ±0.5 mm
- **Max. field size**: 15 x 15 cm
- **Leaf width**: 5 mm at isocenter, (physical 2.5 mm)
- **Gantry bore diameter**: 125 cm at MLC, 200 cm elsewhere
- **Beam-on time**: ≤ 0.3 sec
- **Beam stability**: < 0.2%
- **Beam-stopper**: Material: steel covers entire field
- **Isocenter clearance**: 40 cm
Vero - Motion

+/- 185 degrees of rotation of the linear accelerator
+/- 60 degrees of rotation of the outside ring structure
+/- 2.5 degrees of rotation of the gimbaled MLC/Linac unit

Slide courtesy of BrainLAB
Vero - Imaging capabilities

Extremely rigid O-Ring structure

Dual diagnostic imaging capabilities

→ **Stereo x-ray**, dual fluoro and Cone Beam CT
Vero - Imaging capabilities

Extremely rigid O-Ring structure

Dual diagnostic imaging capabilities

→ Stereo x-ray, **dual fluoro** and Cone Beam CT
Vero – Imaging capabilities

Extremely rigid O-Ring structure

Dual diagnostic imaging capabilities

→ Stereo x-ray, dual fluoro and **Cone Beam CT**
Vero - Imaging capabilities

Extremely rigid O-Ring structure
Dual diagnostic imaging capabilities
6 MV C-Band linear accelerator & MLC
Real-time EPID MV imaging
±2.5 degrees (4.4cm @ iso) of rotation of the gimbaled MLC/Linac unit

Enables dynamic tracking
Dynamic Tumor Tracking

PATIENT TREATMENT

Mode 1
Tracking based on IR breathing signal.

Mode 2
Real-time tumor tracking

SWITCH MODE ANY TIME

Slide courtesy of BrainLAB
Dynamic Wave Arc

Treatment Delivery Techniques

• Static: Conformal Beam
• Arc: Conformal Arc,
  Dynamic Conformal Arc
  Hybrid Arc
• IMRT: Step & Shoot
  Dynamic
• Dynamic Wave Arc
  • +1DOF in plan optimization
  • No patient/couch motion
  • Combine with Dynamic Tracking

Slide courtesy of BrainLAB
Commissioning and initial stereotactic ablative radiotherapy experience with Vero

Timothy D. Solberg, Paul M. Medlin, Ezequiel Ramirez, Chuxiong Ding, Ryan D. Foster, John Yordy

Department of Radiation Oncology, University of Pennsylvania, Philadelphia, PA; Department of Radiation Oncology, University of Texas Southwestern Medical Center, Dallas, TX, USA
timothy.solberg@uphs.upenn.edu

Table 10. Results from 28 independent end-to-end hidden target tests, 12 performed using 2D/2D (ExacTrac) localization and 16 performed using cone-beam CT localization.

<table>
<thead>
<tr>
<th></th>
<th>Anterior–Posterior</th>
<th>Right–Left</th>
<th>Superior–Inferior</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ave</td>
<td>Min</td>
<td>Max</td>
</tr>
<tr>
<td>All Data (n=28)</td>
<td>0.00</td>
<td>-0.67</td>
<td>0.79</td>
</tr>
<tr>
<td>2D/2D (n=12)</td>
<td>0.14</td>
<td>-0.67</td>
<td>0.79</td>
</tr>
<tr>
<td>CBCT (n=16)</td>
<td>-0.09</td>
<td>-0.49</td>
<td>0.48</td>
</tr>
</tbody>
</table>

Fig. 7: Planned dose distributions for RPC head and neck IMRT, spine and thorax phantoms (left to right).

EDGE Platform

- Photon only TrueBeam
  - Maestro control system
- 6X/6XFFF & 10X/10XFFF
- 6-DOF couch
- OBI
- HD120™ MLC
- DR: 2400MU/min (10FFF)
- Intrafraction motion
  - SIG
  - Calypso®
PerfectPitch Couch

- Characteristics
  - Robotic alignment with 6 degrees of freedom
  - Correction limits
    - $\pm 3^\circ$ pitch, roll, & yaw
    - $\pm 50$mm lat. & long.
    - $\pm 25$mm vert
  - Isocentric rotation
  - Supports up to 330 lbs
  - Fully integrated in the EDGE Suite
  - Sub-millimeter accuracy

Slide courtesy of Varian
Intracranial SRS

Intracranial Treatment Solution

- Optical Surface Monitoring System (OSMS)
- Integrated Conical Collimator & Verification System (ICVI)
- Eclipse™ Cone Planning
- SRS Immobilization Accessories Package from Qfix™

Supports

- Frameless and frame-based SRS delivery
OSMS Features

- Non-ionizing
- Real-time surface tracking
- Monitor patient motion after patient set up has been completed
- Real time, accurate assessment of target location during beam delivery
Integrated Conical Collimator Verf.

- Automatic and electric correlation to plan requirements
- An incorrect cone size triggers an interlock which may increase patient safety
- Automatic record of match in ARIA™
- Includes 7 conical collimators
  - 4, 5, 7.5, 10, 12.5, 15, 17.5 mm
Extracranial Localization

- Integrated, direct, real-time tumor tracking with the Calypso® system
  - Optimized for extracranial radiosurgery
    - Increased position update rate
    - Marker implantation equipment and training
- Immobilization package from Qfix
- Gating marker block for surface tracking
ViewRay™ Platform

- 4D, real-time MR imaging
- Split 0.35T-MR
- 3 - $^{60}$Co sources
- MLC-based
- Isocentric (MR & RT)
- Real-time adaptive planning
ViewRay Components

- MR FOV 50cm
- Robotic $^{60}$Co sources
  - 120° apart
  - DR: 550cGy/min
  - FS: 10.5×10.5 cm$^2$
- Doubly focused MLC
  - Reduces $^{60}$Co penumbra

ViewRay Features

- MR-based tracking to gate delivery based on soft tissue detection
- Integrated adaptive TPS
  - A priori MC based
  - On-couch ART
- Real-time adaptive tools
  - Deformable registration
  - Dose re-optimization
ViewRay - SRT Implications

• SABR techniques
  – Lung, Liver, Pancreas….

• Reasons….
  – Lesion tracking (visualization of lesion)
  – Sensitive OARs
  – Breathing motion (MR tracking)
  – Deformation (online deformation tools)
Summary | Conclusion

• Modern SRT dedicated system have proven to obtain high accuracy and precision in radiation delivery
• Incorporate of high quality imaging systems improve patient positioning and monitoring
• Significant improvements in system design and delivery capabilities have allowed for faster, more efficient delivery
Thank you for your time and attention.