Varian Edge Experience

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Henry Ford Health System
Disclosures

- I participate in research funded by Varian Medical Systems.
Outline of Presentation

• Review advanced imaging in Varian Edge Linear Accelerator, and share initial experiences.
Edge at Henry Ford for Radiosurgery

- **E:** 6XFFF, 10XFFF (2400MU/min), 2.5XFFF, HD120MLC
- **kV Source**
- **kV Detector**
  - 40x30 cm²
- **MV Detector**
  - aS1200, 43x43 cm²
- **Calypso x3**
- **OSMS x 3**
- IR camera for gating
- **Gating marker block**
- **Calypso**
- **PerfectPitch® 6D Couch**
Machine Isocentricity

- Machine isocentricity is one of the important aspect of small target radiosurgery.

<table>
<thead>
<tr>
<th>Performance Specifications</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gantry and collimator isocenter accuracy</td>
<td>≤ 0.5 mm radius</td>
</tr>
<tr>
<td>Gantry, collimator, and couch isocenter accuracy</td>
<td>≤ 0.75 mm radius</td>
</tr>
</tbody>
</table>

- Measured values using three different methods.

<table>
<thead>
<tr>
<th></th>
<th>Isolock (6XFFF)</th>
<th>Isocal (6xFFF)</th>
<th>MPC (6XFFF)</th>
<th>MPC (10XFFF)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gantry+Col</td>
<td>0.27mm</td>
<td>0.30mm</td>
<td>0.34mm</td>
<td>0.33mm</td>
</tr>
<tr>
<td>Gantry+Col+Couch</td>
<td>0.44mm</td>
<td>-</td>
<td>0.64mm</td>
<td>0.60mm</td>
</tr>
</tbody>
</table>

# Analysis was done by Varian Medical System. MPC – machine performance check.
Advanced Imaging

- Multi-Scan (stitched/extended length) CBCT
- 2.5 MV Imaging
- Motion management
  - Triggered Imaging/Auto beam hold
  - 4D CBCT
  - Gating
  - MV cine imaging
- OSMS (Optical Surface Monitoring System)
- Calypso (GPS for the body)
- 2D/3D auto-match
Topics

Topics to cover in this talk:

1. **Multi-Scan (stitched/extended length) CBCT**
2. Triggered Imaging/Auto beam hold
3. 4D CBCT
4. 2.5 MV Imaging
Multi-Scan CBCT

• Acquire multiple CBCT scans with couch shift
  → combine them to single CBCT (Advanced Reconstructor).

• Goal is to overcome the small FOV in the sub/inf view.
  – Typical CBCT is <20.0 cm long along sup/inf
    • due to the limited detector dimension (WxH = 40x30 cm²)

• Useful for large target treatment such as H&N area.

• Useful for estimating dose of day calculation on CBCT images (ART)
Multi-Scan CBCT

Phantom

Acquire two consecutive scans and stitch them to create one

Couch shift = 15.5 cm
Multi-Scan CBCT

- QA concerns/checks for commissioning
  - Geometric integrity check
    - There should be no distortion/shear/scale anomaly
    - Table motion accuracy
      - Ideally, there should be a per-scan verification
        - Such as imaging a surrogate object with known geometry
        - Or, monitor table motion using OSMS.
  - Imaging dose check
    - The overlap area should get sufficiently small dose.
  - HU accuracy.
Multi-Scan CBCT

- Visual comparison between CT and extended multi-scan CBCT

Red – CT
Green – Multi-Scan CBCT
Multi-Scan CBCT

Dose of each sub-scan should be lower than conventional CBCT scans to make the dose in the overlap sufficiently small.
Multi-Scan CBCT

Table 12: kV CBCT Specifications
All scale references below are per IEC 61217 – Deployed CBCT modes

<table>
<thead>
<tr>
<th></th>
<th>Head</th>
<th>Pelvis</th>
<th>Spotlight</th>
<th>Thorax</th>
<th>Image Gently</th>
<th>Pelvis Obese</th>
<th>4D Thorax</th>
<th>4D Spotlight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage [kVp]</td>
<td>100</td>
<td>125</td>
<td>125</td>
<td>125</td>
<td>80</td>
<td>140</td>
<td>125</td>
<td>125</td>
</tr>
<tr>
<td>Tube current [mA]</td>
<td>15</td>
<td>60</td>
<td>60</td>
<td>15</td>
<td>20</td>
<td>75</td>
<td>40</td>
<td>40</td>
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<tr>
<td>Pulse duration [ms]</td>
<td>20</td>
<td>20</td>
<td>25</td>
<td>15</td>
<td>20</td>
<td>25</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Frame rate [fps]</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>10</td>
<td>25</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Scan arc [deg]</td>
<td>200</td>
<td>360</td>
<td>200</td>
<td>360</td>
<td>200</td>
<td>360</td>
<td>200</td>
<td>200</td>
</tr>
<tr>
<td>Gantry rotation speed [deg/s]</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Scan duration [s]</td>
<td>33</td>
<td>60</td>
<td>33</td>
<td>60</td>
<td>33</td>
<td>60</td>
<td>120</td>
<td>67</td>
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<tr>
<td>Number of projections</td>
<td>500</td>
<td>900</td>
<td>500</td>
<td>900</td>
<td>500</td>
<td>900</td>
<td>840</td>
<td>467</td>
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<tr>
<td>Exposure (mAs)</td>
<td>150</td>
<td>1080</td>
<td>750</td>
<td>270</td>
<td>150</td>
<td>1688</td>
<td>672</td>
<td>373</td>
</tr>
<tr>
<td>CTDIw, norm [mGy / 100 mAs]</td>
<td>1.95</td>
<td>1.32</td>
<td>1.34</td>
<td>1.32</td>
<td>0.84</td>
<td>1.64</td>
<td>1.32</td>
<td>1.34</td>
</tr>
<tr>
<td>CTDIw (mGy)</td>
<td>2.93</td>
<td>14.3</td>
<td>10.1</td>
<td>3.56</td>
<td>0.84</td>
<td>27.7</td>
<td>8.87</td>
<td>5.00</td>
</tr>
<tr>
<td>Fan type</td>
<td>Full fan</td>
<td>Half fan</td>
<td>Full fan</td>
<td>Half fan</td>
<td>Full fan</td>
<td>Half fan</td>
<td>Half fan</td>
<td>Full fan</td>
</tr>
<tr>
<td>Default pixel matrix</td>
<td>512 x 512</td>
<td>512 x 512</td>
<td>512 x 512</td>
<td>512 x 512</td>
<td>512 x 512</td>
<td>512 x 512</td>
<td>512 x 512</td>
<td>512 x 512</td>
</tr>
<tr>
<td>Slice thickness [mm]</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
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<tr>
<td>Ring suppression algorithm</td>
<td>Medium</td>
<td>Medium</td>
<td>Medium</td>
<td>Medium</td>
<td>Medium</td>
<td>Medium</td>
<td>Medium</td>
<td>Disabled</td>
</tr>
</tbody>
</table>

Ref: “Edge Radiosurgery System” spec sheet
## Multi-Scan CBCT

### Sample measured data

#### CTDI (Edge CBCT – normal single CBCT scan)

<table>
<thead>
<tr>
<th>Protocol</th>
<th>kV</th>
<th>mAs</th>
<th>Rotation Time (s)</th>
<th>Beam Width (mm)</th>
<th>Predicted CTDI (mGy)</th>
<th>Predicted nCTDI (per 100 mAs) (mGy)</th>
<th>Center Position Average Chamber Reading (mGy)</th>
<th>12:00 Position Average Chamber Reading (mGy)</th>
<th>Measured nCTDlw (per 100 mAs) (mGy)</th>
<th>Predicted vs. Measurement (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chest Based</td>
<td>120</td>
<td>1440</td>
<td>60</td>
<td>23.5</td>
<td>19.00</td>
<td>1.32</td>
<td>2.9</td>
<td>4.0</td>
<td>1.08</td>
<td>22.1%</td>
</tr>
<tr>
<td>Large Pelvis Based</td>
<td>140</td>
<td>1687.5</td>
<td>60</td>
<td>23.5</td>
<td>27.70</td>
<td>1.64</td>
<td>4.7</td>
<td>6.3</td>
<td>1.45</td>
<td>13.3%</td>
</tr>
<tr>
<td>Head</td>
<td>100</td>
<td>1000</td>
<td>33</td>
<td>23.5</td>
<td>19.50</td>
<td>1.95</td>
<td>4.3</td>
<td>3.4</td>
<td>1.59</td>
<td>23.0%</td>
</tr>
<tr>
<td>4D CTDI Thorax</td>
<td>125</td>
<td>2880</td>
<td>120</td>
<td>23.5</td>
<td>38.00</td>
<td>1.32</td>
<td>5.8</td>
<td>8.0</td>
<td>1.07</td>
<td>23.4%</td>
</tr>
</tbody>
</table>

#### CTDI of CT scanner (Philips, Brilliance BigBore CT Scan)

<table>
<thead>
<tr>
<th>Protocol</th>
<th>kV</th>
<th>mAs</th>
<th>Rotation Time (s)</th>
<th>Beam Width (mm)</th>
<th>Predicted CTDI (mGy)</th>
<th>Predicted nCTDI (per 100 mAs) (mGy)</th>
<th>Center Position Average Chamber Reading (mGy)</th>
<th>12:00 Position Average Chamber Reading (mGy)</th>
<th>Measured nCTDlw (per 100 mAs) (mGy)</th>
<th>Predicted vs. Measurement (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modified Onco Pelvis</td>
<td>120</td>
<td>250</td>
<td>0.50</td>
<td>12</td>
<td>14.50</td>
<td>5.80</td>
<td>1.2</td>
<td>2.5</td>
<td>6.89</td>
<td>-15.8%</td>
</tr>
<tr>
<td>Chest Based</td>
<td>120</td>
<td>400</td>
<td>1.00</td>
<td>24</td>
<td>21.10</td>
<td>5.28</td>
<td>3.3</td>
<td>7.4</td>
<td>6.26</td>
<td>-15.7%</td>
</tr>
<tr>
<td>Large Pelvis Based</td>
<td>140</td>
<td>500</td>
<td>1.50</td>
<td>24</td>
<td>38.20</td>
<td>7.64</td>
<td>6.2</td>
<td>13.1</td>
<td>9.01</td>
<td>-15.2%</td>
</tr>
</tbody>
</table>

# CBCT dose is lower than simulation dose for this particular set of scanners.
**Multi-Scan CBCT**

**Table I. Test specifications for radiation and patient safety.**

<table>
<thead>
<tr>
<th>Performance parameter</th>
<th>Test objective</th>
<th>Frequency</th>
<th>Tolerance limits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shielding survey</td>
<td>To verify exposure levels around the CT-scanner room</td>
<td>Initially</td>
<td>NCRP recommendations or applicable regulatory limits</td>
</tr>
<tr>
<td>Patient dose from CT-scan, CTDI</td>
<td>To verify safe dose delivered from the scanner</td>
<td>Annually or after major CT-scanner component replacement</td>
<td>± 20% of manufacturer specifications</td>
</tr>
</tbody>
</table>

**TG - 66**

Topics

1. Multi-Scan (stitched/extended length) CBCT
2. Triggered Imaging/Auto beam hold
3. 4D CBCT
4. 2.5 MV Imaging
Triggered Imaging

- During treatment, additional kV images can be acquired at a specific interval of MU, gantry angle, or time.
- Planning contours (PTV) can be overlaid on the kV image.
- Beam can manually be stopped when needed.
- Useful for intra-fraction motion tracking such as spine radiosurgery.
Triggered Imaging

Sample images from RapidArc Delivery

- DRR and PTV
- $kV$ Source at 270 deg
- $kV$ Source at 45 deg
Auto Beam Hold (ABH)

- ABH is a triggered imaging with automatic marker detection and automatic beam hold.
- Beam ON only when the marker are within an allowed radius.
Auto Beam Hold

Tracking three markers, Diameter = 7mm

Beam ON → Beam ON → Beam Off

Motion Phantom
Auto Beam Hold

Test with a Rando phantom for robustness check.
Auto Beam Hold

Marker False Detection

$\rightarrow$ Auto Beam Hold can be turned off.

Marker Not Found
Auto Beam Hold

- An alternative to ABH, if marker detection algorithm is not robust(faulty), is the triggered imaging with structure overlay.

Manual Beam Hold
Triggered Imaging

The PolyMark™ Marker is the first biocompatible polymer-based marker. The PolyMark can be visualized using MRI, minimizes artifact and is visible using kV based IGRT solutions.

| Sterile Placement Needle (1.0GA ETW x 20cm) with (1 x 3mm) PolyMark Marker | 1 | MTCTXPM101820 |
| Sterile Loose (0.8 x 3mm) PolyMark Marker | 4 | MTCTXPM0834 |
Topics

1. Multi-Scan (stitched/extended length) CBCT
2. Triggered Imaging/Auto beam hold
3. **4D CBCT**
4. 2.5 MV Imaging
4D CBCT

1. Place a gating marker block on patient chest during CBCT acquisition.
2. Reconstruct a 4D CBCT using Advanced Reconstructor (offline).
4D CBCT Sample
4D CBCT
Sample (Animation)

Coronal

Sagital
Topics

1. Multi-Scan (stitched/extended length) CBCT
2. Triggered Imaging/Auto beam hold
3. 4D CBCT
4. **2.5 MV Imaging**
2.5 MV Imaging (FFF)

- Imaging only, not for treatment.
- More photoelectric and less Compton interaction than 6 MV.
- Better penetration than kV.
- 2.5 MV portal imaging is comparable with KV imaging in contrast and resolution for moderate size phantoms [1].
- The 2.5 MV imaging is a good alternative to KV in imaging large patients[1].

2.5 MV Imaging (FFF)

2.5 MV Las Vegas  
2.5 MV imaging is better than 6 MV imaging in both resolution and contrast

6 MV Las Vegas

Song et al, “Quantitative Analysis of 2.5 MV Portal Imaging Performance Compared to KV and 6MV Portal Imaging On the Novel Edge LINAC” SU-E-J-147, AAPM 2014, Austin, TX.
Leeds phantom contrast test with 10 cm solid water

2.5 MV Imaging (FFF)

Song et al, SU-E-J-147, AAPM 2014, Austin, TX.
2.5 MV Imaging (FFF)

Song et al, SU-E-J-147, AAPM 2014, Austin, TX.
2.5 MV Imaging (FFF)

High contrast resolution

- KV Resolution 50kVp20mA20ms
- KV Resolution 75kVp20mA20ms
- KV Resolution 75kVp40mA20ms
- 2.5MV Resolution
- 6MV Resolution

Low contrast resolution

- KV Contrast 50kVp20mA20ms
- KV Contrast 75kVp20mA20ms
- KV Contrast 75kVp40mA20ms
- 2.5MV Contrast
- 6MV Contrast

Song et al, SU-E-J-147, AAPM 2014, Austin, TX.
Song et al, SU-E-J-147, AAPM 2014, Austin, TX.
2.5 MV Imaging (FFF)

Rando chest phantom CNRs

CNR = \frac{|mean(S) - mean(B)|}{std(B)}

Song et al, SU-E-J-147, AAPM 2014, Austin, TX.
2.5 MV Imaging (FFF)

<table>
<thead>
<tr>
<th>120 Kilo Voltage</th>
<th>2.5 Mega Voltage</th>
<th>6 Mega Voltage</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 cm solid water</td>
<td>0 cm solid water</td>
<td>0 cm solid water</td>
</tr>
<tr>
<td>5 cm solid water</td>
<td>5 cm solid water</td>
<td>5 cm solid water</td>
</tr>
</tbody>
</table>

Song et al, SU-E-J-147, AAPM 2014, Austin, TX.
2.5 MV Imaging (FFF)

Brainlab Pelvis Phantom

Contrast-to-noise ratio [CNR]

Additional thickness of solid water slab [cm]

Song et al, SU-E-J-147, AAPM 2014, Austin, TX.
Q. What is the recommended frequency of the CTDI measurement for CT simulators by AAPM TG 66?

0% 1. Once at Commissioning

84% 2. Annually, or after major component replacement

14% 3. Monthly, or after major component replacement

1% 4. Weekly, or after major component replacement

1% 5. Daily, or after major component replacement
Q. What is the recommended frequency of the CTDI measurement for CT simulators by AAPM TG 66?

Answer: 2). Frequency recommended by TG66: Annually or after major CT-scanner component replacement.

Thank you for your attention