**kV- & MV-CBCT Imaging for Daily Localization: Commissioning, QA, Clinical Use, & Limitations**

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**Team Work**

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Siemens Medical Solutions

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**In RT, We Ask the Questions**

- Disease Stage (local, regional, metastatic)
- Tumor location
- Edge of the tumor volume
- Nodes involvement
- Tumor within Rx fields
- OARs location
- Modulate the intensity to maximize the therapeutic ratio

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**In-Room Imaging Technologies**

- CT on rails
- 2D kV Imaging
- kV CB Imaging
- MV-CT Imaging
- kV & MV CB Imaging

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CBCT Imaging in a Nut Shell

- Imaging of the tumor and surrounding OARs prior to Rx
- Physicians can immediately compare Rx images to planning CT images to ensure accurate Rx delivery
- CBCT provides a 3D image of the tumor, so its depiction is more accurate and precise than with traditional 2D images
- CBCT allows us to refine the treatment plan during the course of treatment to adapt to changes in the tumor's size

Mega-Voltage CBCT

- MV-CBCT features & characteristics
- The image quality vs. exposure challenge...
- ... and an elegant workaround
- MV-CBCT as a localization system
- Thinking outside the box
- QA
- Clinical experience
- Conclusions

MV-CBCT Basics

- Volumetric patient image using a 6x beam
- High sensitivity a-Si panel
- Synchronization of beam pulse & panel read out
- Gantry rotation of 200 degrees
- Time: acquisition ~ 50 sec & recon. ~ 1 min
- 27 cm³ max FOV (FS 27.4 x 27.4 cm & SID @ 145 cm)
- Slice thickness range: 1 mm to 5 mm
- CT image sizes: 128², 256² or 512² pixels
- Dose delivered 3 cGy - 12 cGy

Characteristics of MV-CBCT

- 3, 5, 8, 10, 12, & 15 MU delivery protocols (0.01-0.1 MU per projection)
MV-CBCT Configuration

- CB Protocol Name
- MUs (1-200): 4, 10, 15 MU
- Slice Size: 128x128, 256x256, 512x512
- Slice Thickness: 0.5 to 10 mm
- Reconstructing Kernel: Smoothing, Smoothing H&N, Smoothing pelvis

MV-CBCT Work Flow

MV-CBCT Localization

- Acquisition
- Table offsets
- 4-6 minutes
- An Integrated System

Image Registration

- Planning CT and CBCT
- Table offsets
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Image Contrast vs. Exposure

CNR vs. Dose for 7 MU Protocols and 3 Materials

Resolution vs. Exposure

- Smallest visible bar group was 0.3 lp/mm for the 3 & 5 MU protocols
- 0.4 lp/mm for all other protocols
- kV-CT was 0.6 lp/mm
**Improved Contrast & Resolution at Higher Doses But...**

2.5 cGy 9 cGy

**Sufficient bony anatomy at 2.5 cGy**

**Prostate Patient**

2.5 cGy 9 cGy 10 cGy at isocenter

**Dose Verification & Simulation**

<table>
<thead>
<tr>
<th>Phantom Diam.</th>
<th>16 cm</th>
<th>32 cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>MV Protocol</td>
<td>10 MU</td>
<td>15 MU</td>
</tr>
<tr>
<td>Meas</td>
<td>7.9</td>
<td>8.1</td>
</tr>
<tr>
<td>Calc</td>
<td>8.2</td>
<td>8.5</td>
</tr>
<tr>
<td>Isocenter</td>
<td>10.3</td>
<td>10.2</td>
</tr>
<tr>
<td>90°</td>
<td>8.9</td>
<td>8.7</td>
</tr>
<tr>
<td>180°</td>
<td>6.9</td>
<td>4.1</td>
</tr>
<tr>
<td>270°</td>
<td>8.3</td>
<td>8.3</td>
</tr>
</tbody>
</table>

Measurements and calculations are within 0.5 cGy

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Model the CB imaging beam as an arc beam

Imaging CB Dose Distributions

15 MU Protocol

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DVHs w & w/o MV-CBCT

Plan w/o CB

Plan w/ CB


Plan without CB

Plan with CB

IMRT Incorporating Dose from MV-CBCT
US vs. MV-CBCT vs. FM for Prostate

**US:** 696 couch alignments for 19 patients

**CBCT:** 598 couch alignments for 17 patients

**FM:** 393 couch alignments for 12 patients

### Prostate Systematic & Random Errors

<table>
<thead>
<tr>
<th>Localization method</th>
<th>AP (mm)</th>
<th>LR (mm)</th>
<th>SI (mm)</th>
<th>3D shift (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>US</strong></td>
<td>-10±5.2</td>
<td>-12±6.8</td>
<td>-2.8±5.1</td>
<td>3.8±6.2</td>
</tr>
<tr>
<td><strong>MV-CBCT</strong></td>
<td>-0.3±3.9</td>
<td>10±3.9</td>
<td>-1.3±2.5</td>
<td>5.3±3.4</td>
</tr>
<tr>
<td><strong>FM</strong></td>
<td>0.5±4.1</td>
<td>-10±3.4</td>
<td>0.0±3.4</td>
<td>5.2±3.7</td>
</tr>
</tbody>
</table>

### Percentage of Shifts Greater than 5 mm

<table>
<thead>
<tr>
<th>Localization method</th>
<th>AP</th>
<th>LR</th>
<th>SI</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>US</strong></td>
<td>38%</td>
<td>34%</td>
<td>31%</td>
</tr>
<tr>
<td><strong>MV-CBCT</strong></td>
<td>62%</td>
<td>18%</td>
<td>6%</td>
</tr>
<tr>
<td><strong>FM</strong></td>
<td>82.5 mm</td>
<td>14%</td>
<td>10%</td>
</tr>
</tbody>
</table>

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**MV-Cine**

- Camera moving around patient
- Data from MV-CBCT is used as fluoroscopic series of portal images to monitor changes on short time scales (e.g., tumor motion)

Individualized, adaptive treatment margins

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**MV-CBCT: Ave Scan Over Time**

- NSCLC, right Upper Lobe, Stage IIIA T2 N2 M0
- MV-CBCT well suited for localization of tumor, but does NOT show tumor motion

**Full Breathing Cycle w/MV-Cine**

- Consecutive projections covering one breathing cycle (range 6° - 15°)
- Diaphragm Movement (2cm)
- Tumor mass moves by 1cm
**Perspective w/MV-Cine**

- Complete MV-cine
  - 270° → 0° → 110°
  - (unlike fluoroscopy)
- Advantage:
  - Quasi 3D view
  - Motion in LR, AP, and SI can be seen

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**QA Procedures & Frequency**

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Daily</th>
<th>Monthly</th>
<th>2x/yr</th>
<th>Device</th>
</tr>
</thead>
<tbody>
<tr>
<td>Position calibration</td>
<td></td>
<td></td>
<td>✓</td>
<td>PI, reticule</td>
</tr>
<tr>
<td>Gain calibration</td>
<td>✓</td>
<td></td>
<td></td>
<td>PI</td>
</tr>
<tr>
<td>Dead pixel map</td>
<td>✓</td>
<td></td>
<td></td>
<td>PI</td>
</tr>
<tr>
<td>EPID image quality</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td>Vegas, FIPSpro</td>
</tr>
<tr>
<td>Horizontal pos. accuracy</td>
<td>✓</td>
<td></td>
<td></td>
<td>PI, reticule</td>
</tr>
<tr>
<td>Vertical pos. accuracy</td>
<td>✓</td>
<td></td>
<td></td>
<td>Ruler</td>
</tr>
<tr>
<td>Geometry calibration</td>
<td>✓</td>
<td></td>
<td></td>
<td>George phantom</td>
</tr>
<tr>
<td>CB gain calibration</td>
<td>✓ (2x)</td>
<td></td>
<td></td>
<td>CB 15, 60 MU</td>
</tr>
<tr>
<td>3D image quality</td>
<td>✓</td>
<td></td>
<td></td>
<td>Ema phantom</td>
</tr>
<tr>
<td>Reconstr. &amp; Registration</td>
<td>✓</td>
<td></td>
<td></td>
<td>Ema phantom</td>
</tr>
<tr>
<td>Dose</td>
<td>✓</td>
<td></td>
<td></td>
<td>Ion chamber</td>
</tr>
</tbody>
</table>

*Goyou and Miften, Med Phys 34, 2383-2394 (2007)*
**MV-CBCT Imaging Numbers**
- MVision in clinical use since June 06
  - An upgrade on a Primus Linac
  - First patient was imaged on 6/5/06
- 226 Patients; ~4000 CBCT scans
  - H&N and Brain: 54
  - Lung/Thorax: 47
  - Spine: 5
  - Prostate: 37
  - Prostate Bed: 17
  - GI/GU: 66
- Total Downtime: 3 days

**Which Patients Should be Imaged with CB?**
- Tumors adjacent to critical structures
- Tumors prone to inter-fractional motion
- Tumors with intra-fractional motion—Preference: 4-D planning
- Tumors prone to deformation
- Compliant patients

**CBCT: Clinical Responsibilities**
- Physician
  - Determine clinical indication(s)
  - Order CBCT
  - Determine frequency
  - Review images (day 1, twice/weeks, daily??)
  - Define primary ROI for physicist/therapist
  - Define set up parameters
  - Review daily shifts

- Physicist
  - Available to review images & shifts daily
  - QA, calibration, output, image quality...etc

- Dosimetrist
  - Dose incorporation

- Therapist
  - Review images
  - Make appropriate table shifts
Ordering a CB for a Patient

- **Physician**: Daily, twice/wk, weekly
- **Physician**: Soft-tissue or bony anatomy
- **Physician**: Imaging protocol 4 MU or 8-15 MU
- **Physician Therapist**: Physician by machine console for 1st Rx

Conclusions

- MV-CBCT is a viable technique for treatment localization
- Observed inter-fractional variations are patient specific and site-dependent
- Application of MV-CBCT for daily localization with good-image quality
- Application of MV-CBCT for verification of intra-fractional motion immediately prior to treatment delivery

SAM: Question 1

The contrast-to-noise ratio (CNR) in MV-CBCT images is proportional to

- 25% 1. dose
- 25% 2. /dose
- 25% 3. 1/dose
- 25% 4. /1dose

SAM: Question 2

MV-CBCT images with improved contrast and high resolution are achievable with doses ≥ 6 cGy and sufficient bony anatomy is feasible at doses

- 25% 1. > 5 cGy
- 25% 2. < 0.5 cGy
- 25% 3. < 1 cGy
- 25% 4. < 0.5 cGy
SAM: Question 3

With MV-CBCT imaging, the anatomical region in patients receiving maximum imaging dose exposure is located

- 25% 1. anteriorly near the surface
- 25% 2. posteriorly
- 25% 3. isocenter
- 25% 4. mid-plane

Thank you