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

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Questions

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

CT on rails

2D kV Imaging

kV CB Imaging

kV & MV CB Imaging

kV CB Imaging

MV-CT Imaging

- helical delivery, similar to spiral CT ± 360 degrees
- binary MLC beam shaping
- on-line MVCT imaging (Tomolmage)
- on-line treatment verification (over 700 individual detectors)
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

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

- 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
**MV-CBCT Configuration**

- **CB Protocol Name**: Cone beam 1SMU
- **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 Localization

Acquisition

Table offsets

Reconstruction

Registration

4-6 minutes
An Integrated System
Image Contrast vs. Exposure

Image Quality Phantom
CNR vs. Dose for 7 MU Protocols and 3 Materials

CNR ~ $\sqrt{\text{dose}}$

$\rho = 1.5$

$\rho = 1.2$

$\rho = 1.09$

35%

15%
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

Sufficient bony anatomy at 2.5 cGy

9 cGy

Better Soft Tissue Contrast

Bony Structures
Patient Imaged w/ 10 cGy
### Dose Verification & Simulation

<table>
<thead>
<tr>
<th>Phantom Diam.</th>
<th>16 cm</th>
<th>32 cm</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>MU Protocol</strong></td>
<td>10 MU</td>
<td>15 MU</td>
</tr>
<tr>
<td><strong>Method</strong></td>
<td><strong>Meas</strong></td>
<td><strong>Calc</strong></td>
</tr>
<tr>
<td><strong>Isocenter</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0°</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>7.1</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

*Gayou, Parda, Johnson, and Miften, Med Phys 34, 499-506 (2007)*
Model the CB imaging beam as an arc beam.
IMRT Incorporating Dose from MV-CBCT
DVHs w & w/o MV-CBCT

IMRT Plan w/o CB

IMRT Plan w/ CB

Patient A

Patient B

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
US vs. MV-CBCT vs. FM for Prostate
Shift Histogram Distribution

Frequency

3D distance (mm)

0 10 20

US  MV-CBCT  FM
## Prostate Systematic & Random Errors

<table>
<thead>
<tr>
<th>Localization method</th>
<th>AP (mm)</th>
<th>LR (mm)</th>
<th>SI (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>US</strong></td>
<td>-1.0 ± 5.9</td>
<td>-1.2 ± 6.8</td>
<td>-2.8 ± 5.1</td>
</tr>
<tr>
<td><strong>MV-CBCT</strong></td>
<td>-0.3 ± 3.9</td>
<td>1.0 ± 3.9</td>
<td>-1.3 ± 2.5</td>
</tr>
<tr>
<td><strong>FM</strong></td>
<td>0.5 ± 4.1</td>
<td>-1.0 ± 3.4</td>
<td>0.0 ± 3.4</td>
</tr>
</tbody>
</table>
Percentage of Shifts Greater than 5 mm

Prostate PTV Margins

<table>
<thead>
<tr>
<th>Localization Method</th>
<th>AP</th>
<th>LR</th>
<th>SI</th>
</tr>
</thead>
<tbody>
<tr>
<td>MV-CBCT</td>
<td>16%</td>
<td>18%</td>
<td>6%</td>
</tr>
<tr>
<td>US</td>
<td>38%</td>
<td>34%</td>
<td>31%</td>
</tr>
<tr>
<td>CB</td>
<td>16%</td>
<td>18%</td>
<td>6%</td>
</tr>
<tr>
<td>FMFM</td>
<td>20%</td>
<td>14%</td>
<td>10%</td>
</tr>
</tbody>
</table>

van-Herk formula: \[ M = 2.5\Sigma + 0.7\sigma \]

Prostate PTV Margins

- US data: 12.4 mm
- CB data: 8.2 mm
- FMFM data: 20.5 mm

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

1 cm peripheral lung mass
Patient treated w/ 3DCRT

5 cm lung mass
PTV Margin: 5mm, 10mm
Patient treated w/ IMRT

Motion in LR, AP, & SI can be seen

Reitz, Gayou, Parda, and Miften PMB 53, 823-836 (2007)
## 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, PIPSpro</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></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>

Gayou and Miften, Med Phys 34, 3183-3192 (2007)
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
CBCT: Clinical Responsibilities

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

- **Dosimetrist** -
  - Dose compensation or 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

**Physicist**
- Imaging protocol
  - 4 MU or 8-15 MU

**Physicist**
- Physician by machine console for 1st Rx

**Frequency**

**Registration**

**Exposure**

**Review & Thresholds**
Workflow: Physician EMR Order
IGRT at the Clinic Practice Level

- Therapist oversight and competencies
- Hybrid imaging schedules
- Improve immobilization and patient marking processes
- Additional CBCT devices are needed to handle clinical needs
- Use CBCT to implement more sophisticated ART techniques
- Decrease PTV
- Improve clinical outcomes
Conclusions

• MVision is a viable tool 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 Tx
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