MV Cone Beam CT Imaging for daily localization: (part II)

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AAPM CE-Therapy Series Panel Session
7h30 - 9h25 am, July 28th, 2009
Course Objectives

MV Cone Beam CT Imaging for daily localization: (part II)

4- Complement standard clinical applications
   a- Daily prostate alignment
   b- Alignment and target delineation in presence of metallic objects

5- Introduce novel clinical applications
   a- Concurrent treatment of prostate and pelvic lymph nodes
   b- MVCB Digital Tomosynthesis

6- Present technology evolution and future directions
   a- Imaging Beam Line (Diamond View)
   b- Accurate Dose Recalculation and the DGRT Process
Why MVCBCT for pelvic patients?

- Faster, objective and less dose than EPID + markers
  - 3-4 minutes
  - 2-3 cGy

- Provides additional 3D information
  - Volumetric info: Rectum, bladder, etc.
  - Prostate contours -> Dose recalculation
Alignment and target delineation in presence of metallic objects

- Imaging in presence of Hip Prostheses
  - Target delineation
  - electron density
  - marker visualization

- Prostatectomy patients
  - Surgical clips vs markers

- HDR Brachytherapy
  - Target delineation
  - Non-compatible CT applicators


Spinal cord delineation with MVCBCT registered to CT for planning purpose, for a patient with a metallic supporting structure.
5- Novel clinical applications

a- Concurrent treatment of prostate and pelvic lymph nodes with IMRT+IGRT
b- Digital Tomosynthesis
5-a: Concurrent treatment of prostate and pelvic lymph nodes with IMRT

**Challenge:** Independent movements of prostate vs nodes

![Graphs showing daily setup error and daily prostate movement](image)

![_images showing plan, iso shift, and prostate-MLC shift](image)

Courtesy of Ping Xia, UCSF 2007
ADAPTIVE STRATEGY using Daily MvCBCT for Pelvic Nodal Irradiation in the Treatment of Prostate Cancer

1- CT-MvCBCT registered on bony structures: -> patient aligned accordingly: setup error

2- CT-MvCBCT registered on gold markers -> prostate shift is the difference between these two alignments

3- Select and treat with a (pre-calculated) plan according to relative prostate shift
   - Set of pre plans with iso shifts (iso)
   - Shifting selected MLC leaves (mlc)
   - Re-optimization of the plan (reopt)
5-b: MVCB Digital Tomosynthesis

MVCBDT is a limited arc MVCBCT (20°-40° vs. 200°)

- **2D**
  - low contrast
  - fast acquisition
  - (few seconds)
  - 1-3 MU

- **Some 3D**
  - Better contrast than EPID
  - faster acquisition and lower dose than CB

- **True 3D**
  - longer acquisition
  - (~1 minute)
  - 2-10 MU
Limited reconstruction arc results in tomographic noise, which increases as the arc decreases:

- Out of focus structures are reconstructed on the plane of interest ➔ slice thickness
- Shape distortion

Descovich M., Morin O., Aubry J.F., Aubin M., Chen J., Bani-Hahemi A. & Pouliot J.

Clinical Images

- **EPID**: only 2D information, poor contrast
- **DTS**: spatial blur, better contrast
- **CBCT**: thin slices, improved contrast
**MVCB Digital Tomosynthesis**

Sagittal head and neck DT image registered to planning CT (40° arc, 3 cGy)

Coronal lung DT image registered to planning CT (40° arc, 5 cGy)

Images Courtesy of M. Descovich, UCSF
MVCB Digital Tomosynthesis

Geometry of breast phantom image acquisition (40° DT arcs).

Tangent Field

Planning CT

DT Tangent

- Extended clearance
- Low acquisition dose
- Short acquisition time (~10 sec)
- No dose to contralateral breast

Acquisition dose: 0.3 cGy
Dose on the contralateral breast was 0.07 cGy
• Image quality in DT depends on the reconstruction arc.

• MVCB DT image quality is sufficient to provide anatomical information and might be suitable for registration purposes.

• Advantages:
  - Only a portion of the patient body gets exposed
  - Faster
  - Smaller dose

• Possible clinical application: Lung and Breast treatment verification
  - Reduce the motion blur in imaging moving targets
  - Acquire images during breath-holding
  - Online verification of 4D and respiratory gating techniques

**SU-FF-I-48: Optimization of Image Acquisition Parameters for Patient Setup Using Megavoltage Cone-Beam Digital Tomosynthesis, Descovich et al.,**
6- Technology evolution and future directions

a- Imaging Beam Line (Diamond View)
b- Accurate Dose Recalculation and the DGRT Process
How Well Are The Technologies Working?

**Image Quality**

- Contrast
- Noise
- Contrast to noise ratio
- Uniformity
- Spatial resolution
- Stability
- Linearity

- Patient setup ?
- Dose recalculation ?
- Target and organ delineation ?
- Dose accumulation ?

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Jean Pouliot  UCSF

Sunday, July 12, 2009
### Tables

Table 1. Technical characteristics of MVCBCT imaging. The bold font specifies the typical values used in the baseline image acquisition and reconstruction protocol.

<table>
<thead>
<tr>
<th>MVCBCT Characteristics</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Acquisition geometry</strong></td>
<td></td>
</tr>
<tr>
<td>Source-to-axis distance (SAD)</td>
<td>100.0 cm</td>
</tr>
<tr>
<td>Source-to-imager distance (SID)</td>
<td>145.0 cm</td>
</tr>
<tr>
<td>Cone angle</td>
<td>7.8°</td>
</tr>
<tr>
<td>Maximum projection field size</td>
<td>27.4 x 27.4 cm²</td>
</tr>
<tr>
<td>Cranio-caudal imaging length (CIL)</td>
<td>5.0 to 27.0 cm (independent y jaws)</td>
</tr>
<tr>
<td><strong>X-ray beam</strong></td>
<td></td>
</tr>
<tr>
<td>Beam energy</td>
<td>6 MV</td>
</tr>
<tr>
<td>Added filtration</td>
<td>Flattening filter</td>
</tr>
<tr>
<td>Beam output</td>
<td>1 MU = 1 cGy at d_{max} for 10 x 10 field size at 100 SSD</td>
</tr>
<tr>
<td>Available exposure</td>
<td>2.7 to 54 MU (9.0 MU)</td>
</tr>
<tr>
<td><strong>Flat panel imager</strong></td>
<td></td>
</tr>
<tr>
<td>Detection type</td>
<td>Indirect</td>
</tr>
<tr>
<td>Designation</td>
<td>RID 1640 AG9-ES</td>
</tr>
<tr>
<td>Array format</td>
<td>1024 x 1024 pixels</td>
</tr>
<tr>
<td>Converter</td>
<td>1 mm Copper plate</td>
</tr>
<tr>
<td>Scintillator name</td>
<td>Kodak Lanex Fast</td>
</tr>
<tr>
<td>Scintillator material</td>
<td>133 mg/cm² Gd₂O₂S: Tb</td>
</tr>
<tr>
<td>Pixel pitch</td>
<td>0.4 μm</td>
</tr>
<tr>
<td>Area</td>
<td>40.96 x 40.96 cm²</td>
</tr>
<tr>
<td>Nominal frame rate</td>
<td>0.16 frame per second</td>
</tr>
<tr>
<td>Maximum frame rate</td>
<td>7 frames per second</td>
</tr>
<tr>
<td>Readout time</td>
<td>140 ms</td>
</tr>
<tr>
<td><strong>Acquisition procedure</strong></td>
<td></td>
</tr>
<tr>
<td>Number of projections</td>
<td>200</td>
</tr>
<tr>
<td>Angular increments</td>
<td>1°</td>
</tr>
<tr>
<td>Total rotation angle</td>
<td>200°</td>
</tr>
<tr>
<td>Maximum angular rotation rate</td>
<td>1 rotation per minute</td>
</tr>
<tr>
<td><strong>Reconstruction parameters</strong></td>
<td></td>
</tr>
<tr>
<td>Maximum field of view</td>
<td>27.0 x 27.0 x 27.0 cm³</td>
</tr>
<tr>
<td>Reconstruction matrix size (nx, ny, nz)</td>
<td>(128, 256, 512)³</td>
</tr>
<tr>
<td>Voxel size (Δx, Δy, Δz)</td>
<td>(2, 1, 0.5)³</td>
</tr>
<tr>
<td>Slice thickness reconstructed</td>
<td>1, 3, 5 mm</td>
</tr>
<tr>
<td>Backprojection filter</td>
<td></td>
</tr>
<tr>
<td>Projection binning</td>
<td></td>
</tr>
<tr>
<td>Projection filtering</td>
<td></td>
</tr>
<tr>
<td>Uniformity correction</td>
<td></td>
</tr>
<tr>
<td>Slice thickness displayed</td>
<td></td>
</tr>
<tr>
<td>CT normalizing factor $I_0(\theta)$</td>
<td>$I_0(\theta) = I_{0\text{perf}} \times MU(\theta)$ or $I_0(\theta) = \text{mean}(I_{0\text{perframe}})$</td>
</tr>
</tbody>
</table>

Edge enhancing, Edge preserving, **Smoothing**

1 or 2

**Median, Average, Diffusion**

Head and neck, pelvis correction factors

Any, 3 mm
Image Quality Improvement: Ongoing Research

Acquisition
- is 200 projections the optimal number?
- Range of acquisition angles

Optimization of Imaging Beam Line
- Removing of flattening filter
- Low-Z target

Post Processing (filters)
- Image Reconstruction and
- Uniformity correction

More Sensitive a-Si EPID Detectors
- Matching of a-Si EPID for MV Imaging
- Exit Dosimetry for DGRT
Optimizing Image Quality: Post Processing

Table 3.8: CNR performance for different reconstruction protocols. Only the specified protocol component is changed compared to the baseline.

<table>
<thead>
<tr>
<th>Reconstruction Protocol Component</th>
<th>CNR for different rED</th>
<th>Mean CNR</th>
<th>% CNR improvement from baseline</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline (Table 3.1)</td>
<td>51.3% 11.7% 4.3%</td>
<td>8.5</td>
<td>-</td>
</tr>
<tr>
<td>bin = 1</td>
<td>10.8  3.3  1.1</td>
<td>5.1</td>
<td>-40.9</td>
</tr>
<tr>
<td>projfilt = none</td>
<td>12.5  3.8  1.3</td>
<td>5.9</td>
<td>-31.5</td>
</tr>
<tr>
<td>projfilt = Avg. 3x3</td>
<td>14.5  4.5  1.5</td>
<td>6.8</td>
<td>-20.3</td>
</tr>
<tr>
<td>projfilt = Avg. 7x7</td>
<td>21.2  7.4  2.2</td>
<td>10.3</td>
<td>19.9</td>
</tr>
<tr>
<td>projfilt = no Avg., Diffusion</td>
<td>30.8  11.0  3.8</td>
<td>15.2</td>
<td>77.8</td>
</tr>
<tr>
<td>projfilt = Avg. 5x5, Diffusion</td>
<td>34.2  12.5  4.4</td>
<td>17.0</td>
<td>99.3</td>
</tr>
<tr>
<td>bckprojfilt = Edge Enhancing</td>
<td>8.1   2.3  0.8</td>
<td>3.7</td>
<td>-56.2</td>
</tr>
<tr>
<td>bckprojfilt = Edge Preserving</td>
<td>8.6   2.5  0.9</td>
<td>4.0</td>
<td>-53.4</td>
</tr>
<tr>
<td>bckprojfilt = Smoothing low</td>
<td>9.0   2.8  0.8</td>
<td>4.2</td>
<td>-50.8</td>
</tr>
<tr>
<td>nvox = 128x128</td>
<td>13.6  4.6  1.5</td>
<td>6.6</td>
<td>-23.1</td>
</tr>
<tr>
<td>nvox = 512x512</td>
<td>25.0  8.2  2.5</td>
<td>11.9</td>
<td>39.4</td>
</tr>
<tr>
<td>slicethick = 1 mm</td>
<td>10.0  3.3  1.1</td>
<td>4.8</td>
<td>-43.7</td>
</tr>
<tr>
<td>slicethick = 5 mm</td>
<td>23.1  7.2  2.3</td>
<td>10.9</td>
<td>27.5</td>
</tr>
<tr>
<td>$I_{o,0}$ = Mean $I_{operframe}$</td>
<td>17.8  5.8  1.8</td>
<td>8.5</td>
<td>-1.0</td>
</tr>
<tr>
<td>$I_{o,0}$ = Mean $I_{operframe}$ 5% high</td>
<td>17.3  5.7  1.7</td>
<td>8.2</td>
<td>-3.8</td>
</tr>
</tbody>
</table>

Olivier Morin, Jean-François Aubry, Michèle Aubin, Josephine Chen, Martina Descovich, Ali-Bani Hashemi and Jean Pouliot

Optimizing Image Quality: Post Processing

9 MU
256 x 256
Edge Enhancing
3 mm slice thickness

9 MU
256 x 256
Smoothing
3 mm slice thickness

9 MU
512 x 512
Smoothing
3 mm slice thickness
Diffusion
6-a: Imaging Beam Line for MVCBCT (IBL)

- Remove flattening Filter
  - non-uniform illumination
  - smaller focal spot size
  - Do not filter out low-E photons

- Use Carbon Target
  - Generate more low-E photons

- Reduce Beam E to 4 MeV
  - Generate more low-E photons

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Images courtesy of V. Mu, UCSF
6-b: Accurate Dose Recalculation and the DGRT Process

Is the initial plan still valid?  
When to replan?  
What is the dosimetrical impact?

**DGRT is based on the Availability of the 3D Dose Distribution “of the Day”**
Requirements for Dose Recalculation

- **Stability of CT Number**
  - Time
  - Target location
  - Patient size
  - Imaging dose

- **Complete Anatomy**
  - Longitudinal + lateral directions
Cupping artifact correction

**2D: Correcting the projections**
- Monte Carlo models
- Experimental models

**3D: Correcting the reconstructed image**
- Based on phantom measurements -> pelvic
- Based on reference CT image -> H&N
- Based on histogram (T. Boettger) -> Spine, +
Correction of MVCBCT images for dose calculation

Head & Neck MVCBCT images.

a) Uncorrected, b) Corrected, c) Corrected and complemented

Pelvis MVCBCT images.

a) Uncorrected, b) Corrected, c) Corrected and complemented
Correction of MVCBCT images for dose calculation in the head and neck region

- Precise dose calculation with MVCBCT images

Gamma index (3%, 4mm) < 1

SD of calculations between MVCBCT and CT:
1.2% above shoulders
1.9% below shoulders

Integration of workflow

1. Import initial dose plan and MVCBCT image
2. Register the images as patient was treated
3. Correct and complement the MVCBCT image
4. Copy beams from planning CT to MVCBCT
5. Calculate treatment dose
6. Show DVH comparison and dose distributions
7. Display dose difference colored map
8. Use non rigid deformation to map dose grid
9. Accumulate dose

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Quality control based on 3D dose delivered

Dose difference colored maps for head-and-neck patients are made available every week for review of variations in delivered dose during treatment.
Global Comparison

Organ specific comparison (require manual segmentation)

Variation from planning dosimetric endpoints of the parotid glands

Image Deformation used for dose accumulation

Dose distribution of the day is mapped to the original CT dose grid using the non-rigid deformation matrix defined between CT and MVCBCT images.
Automatic warping of spinal cord contours will allow organ specific comparison

Part of an MVCBCT slice overlaid with rigidly matched spinal cord contour (red) and elastically warped contour (green).

Sagittal and axial slice from corrected MVCBCT overlaid with the rigidly registered (red) and the elastically deformed spinal cord contours (green).

Images Courtesy of T. Boettger, Siemens
MVCBCT goes DGRT: Summary

- MV CBCT provides 3D anatomy of patient in treatment position -> Patient setup and tumor targeting, etc.  
  - > IGRT

- MVCBCT allows for dose re-calculation to assess dosimetric impact of anatomical changes, weight loss, tumor shrinkage, etc., and adapt accordingly  
  - > DGRT
Availability of the Dose Distribution “of the Day”

- Assess the dosimetrical impact
e.g. Patient setup, Anatomical change, Tumor shrinkage, Weight loss, etc.

- Global quality assurance “in-vivo”
e.g. Treatment documentation

- More Precise (Delivered-)Dose Response vs Outcomes

- Enables Dose-Guided Radiation Therapy
  DGRT is an extension of ART where dosimetric considerations constitute the basis of treatment modification and validation.