Large Scatter-to-Primary Ratios (SPR) in CBCT cause severe cupping/shading artifacts.

- Wide collimator, high scatter
- Narrow collimator, low scatter

Display window: [min max]; no anti-scatter grid, no scatter correction.


Scatter noise in post-processing methods

- No scatter correction, no noise suppression, Noise in the ROI: 1.01e-6
- Measurement-based scatter correction, no noise suppression, Noise in the ROI: 1.01e-5
- Measurement-based scatter correction, PWLS noise suppression, (Wang et al., 2006) Noise in the ROI: 9.75e-7


Motion artifacts in fan beam CT and CBCT

CBCT using Trilogy

CBCT phantom images

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PWLS (Penalized Weighted Least-Squares method):

$$\Phi(p) = (\hat{y} - \hat{p})^T \Sigma^{-1} (\hat{y} - \hat{p}) + \beta R(p)$$

$$R(p) = \sum_n w_{in} (p_i - p_n)^2$$

$$w_{in} = \exp[-\left(\frac{p_i - p_n}{\delta}\right)^2]$$

Noise property of projection images

Incident X-ray intensities across the field of view with 80 mA tube current and 10 ms pulse time. Relative intensity is mainly caused by the bow-tie filter.

Iterative Gauss-Seidel updating strategy

$$R(p) = \sum_n w_{in} (p_i - p_n)^2$$

$$p_i^{(k+1)} = \frac{y_i + \beta \sigma^2 \left( \sum_{n \in N_i} w_{in} p_n^{(k+1)} + \sum_{n \in N_i} w_{in} p_n^{(k)} \right)}{1 + \beta \sigma^2 \sum_{n \in N_i} w_{in}}$$
Ultra-low dose CBCT

Ultra-low dose fluoroscopic imaging

Metal artifacts removal

Dose Reconstruction: Closing the Loop of IMRT/RapidArc/Gated RapidArc treatment

MLC log-file generated Fluence Map

J. Wang & L. Xing, PMB, 2008


Ultra-low dose fluoroscopic imaging

Metal artifacts removal

J. Wang & L. Xing, X-ray Science & Technology, 2010

Case 1: Dose Distribution

Case 2: Dose Distribution

Case 1: DVHs

Case 2: DVHs

DVH comparison of the intended and delivered plans

DVH comparison of the intended and delivered plans

Dose (cGy)

Relative volume (%)

Dose (cGy)

Relative volume (%)

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### Case 2: Dosimetric comparison

<table>
<thead>
<tr>
<th>Dosimetric and plan</th>
<th>yCT</th>
<th>CBCT1</th>
<th>CBCT2</th>
<th>IDCT1</th>
</tr>
</thead>
<tbody>
<tr>
<td>PTV, D_{max}(Oy)</td>
<td>218.4</td>
<td>217.5</td>
<td>218.2</td>
<td></td>
</tr>
<tr>
<td>PTV, V_{95}(%)</td>
<td>98.2</td>
<td>97.9</td>
<td>98.0</td>
<td>98.0</td>
</tr>
<tr>
<td>Brainstem, D_{max}(Oy)</td>
<td>164.8</td>
<td>171.0</td>
<td>193.1</td>
<td>147.0</td>
</tr>
<tr>
<td>PTV Temporal lobe, D_{max}(Oy)</td>
<td>174.6</td>
<td>173.0</td>
<td>146.0</td>
<td></td>
</tr>
<tr>
<td>LT Temporal lobe, D_{max}(Oy)</td>
<td>174.8</td>
<td>170.4</td>
<td>131.3</td>
<td></td>
</tr>
</tbody>
</table>

220 cGy at 100%

---

### Planned and Reconstructed Dose Profile Comparison

#### R-L profile

Planned and reconstructed dose profiles for different positions.

#### A-P profile

Planned and reconstructed dose profiles for different positions.

---

### Positioning Errors and Dose Delivered to PTV

#### Positioning errors intentionally introduced

- Position #1: same as the plan
- Position #2: L-R: 1 mm; A-P: 2 mm; S-I: 2 mm
- Position #3: L-R: 2 mm; A-P: 4 mm; S-I: 4 mm

---

### Dose Distribution Comparison

#### Plan vs. reconstruction

- CBCT1 / CBCT2: monitored the anatomic change, if any
- CBCTs’ dose distribution very close to pCT’s

---

### Patient Study

- CBCT1 / CBCT2 monitored the anatomic change, if any
- CBCTs’ dose distribution very close to yCT’s
DVH Results

![DVH Graph]

- slight compromise (< 5%) on the target coverage
- dose deposited to the critical organs in general <10% change, worst ~20%

Adaptive Radiation Therapy

- What are needed to bring ART into clinic?
  - CBCT.
  - Deformable model.
  - Automated contour mapping from pCT to CBCT.
  - Retrospective dose reconstruction.
  - Deformable registration for cumulative dose calculation
  - Inverse planning for ART
  - Dose shaping tool.

IMMOBILIZATION DOES NOT ALWAYS WORK!

CBCT imaging of a rectal cancer patient during a course of RT

1st wk (planning CT) 2nd wk 3rd wk (overlay)

4D Treatment Planning

- Static (with 4D CT info - 3.5D RT)
- Gating
- Tracking

Adapted from Y. Yang, UPMC

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Simultaneous kV/MV imaging guided RT delivery
Results – example 1
Real-time Image Guidance for Prostate VMAT/IMRT

Example 1

• The sudden drop represents repositioning.

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