Clinical Applications of CBCT in Proton Therapy

Disclosure

- Received travel funds from IBA in 2015.

The Rational for CBCT in Proton Therapy

- All the advantages of CBCT in photon therapy:
  - Visualization of soft tissue
  - 3D anatomy matching/patient alignment
  - Assessment of tumor size or location
  - Trigger for Adaptive therapy
Gantry Mounted CBCT System (IBA)

- FOV: 34 cm axial and 34 cm longitudinal field of view
- Rotation speed of 0.5 or 1 RPM (full scan or half scan)

Clinical Example - Pelvis

Assessment of Changes in Beam Path

Potential impact of bowel gas along beam path
Qualitative Assessment - Setup

CBCT and CT blended image after orthogonal X-ray setup

CBCT allows for more comprehensive assessment of 3D positioning

Assessment of Daily Organ Filling

Bladder filling

Verification of target position prior to treatment

Qualitative Assessment of Lung CBCT

Identification of anatomical change and soft tissue target localization
Complex Anatomical Change

Pleural effusion

Tumor density change

Other Types of Anatomical Change

Atelectasis

Lung reinflation

Dynamics of Pleural Effusion and Atelectasis

Anatomical change will impact proton range; periodic assessment during treatment is necessary.
Beyond Qualitative Assessment

Tumor regression
Impact on dose distribution to target and organs at risk needs to be assessed

Quantitative Analysis of CBCT

- Proton range assessment
- 3D dose estimation to target and OARs
- Dosimetric and geometric indicators
- Trigger for adaptive proton therapy

Limitations of CBCT for Dose Calculation

- Proton dose calculation is more sensitive to HU uncertainties than photon therapy
- CBCT cannot be used directly for dose calculation unless HU accuracy is verified

If CT number is off by 100 HU
Stopping power is different by 5%
For a 10cm range, error is 5 mm.
Need error in water equivalent depth <<
Range uncertainty of 3.5%
Limitations of CBCT for Dose Calculation

- Beam hardening and scatter artifacts (dark streaks between high density structures, cupping artifacts)
- Motion artifacts (streaking)

Improving Accuracy of CBCT HUs for Dose Calculation

1. Deformable Image Registration (DIR) approach - Deform planning CT to geometry of CBCT
   C Veiga et al, IJROBP 95 549 (2016)

2. A priori CT based scatter correction

From CBCT to a Virtual CT (vCT)

Deform planning CT to geometry of CBCT

Method works in most cases

Limitations:
1. Complex anatomical change not handled correctly by deformable image registration (DIR) software
2. Subtle changes in lung/tumor density not accounted for
C Veiga et al, IJROBP 95 549 (2016)
Correction for Large Tumor Regression

Identify gross DIR errors between CBCT and vCT and replace HU with lung or tissue density.

![Images of CBCT, vCT, and Corrected vCT with annotations]

Correction for Lung Changes

Atelectasis: Not handled correctly by deformable image registration.

![Images of CBCT, vCT, and Corrected vCT with annotations]

Comparison of Virtual CT with Rescan CT

<table>
<thead>
<tr>
<th>Region of Interest</th>
<th>WET(_{\text{mean}}) (mm)</th>
<th>WET(_{\text{RMS}}) (mm)</th>
<th>(\text{WET}_{\text{95%}}) (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distal surface</td>
<td>0.5 ± 2.2</td>
<td>3.7 ± 1.9</td>
<td>8 ± 4</td>
</tr>
<tr>
<td>Proximal surface</td>
<td>0.1 ± 1.9</td>
<td>2.3 ± 1.5</td>
<td>4 ± 3</td>
</tr>
<tr>
<td>PTV</td>
<td>6.4 ± 3.1</td>
<td>3.6 ± 2.0</td>
<td>7 ± 4</td>
</tr>
</tbody>
</table>

WET: Water Equivalent Thickness from entrance of beam to target.

- Mean difference in WET is about 1 mm.
- Possible to estimate shifts in range with 2 to 3 mm accuracy.

C Veiga et al, IJROBP 95 549 (2016)
**Fast Online Dose Estimation**

Deform TPS dose for each field based on change in WET

- Over-ranging
- Under-ranging
- No Change

C Veiga et al. IJROBP 95 S49 (2016)

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**Traditional Analysis with vCT**

Feasible to replace evaluation CTs with CBCT

IJROBP Veiga et al 2016

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**Summary:**

- Patient setup and 3D anatomical assessment (qualitative) will be primary use of CBCT
- Quantitative analysis requires accurate HUs in CBCT
- CBCT may be used to determine need for adaptive therapy