Clinical Applications of CBCT in Proton Therapy

B Kevin Teo, PhD
AAPM 2016

PENN RADIATION ONCOLOGY
Penn Medicine

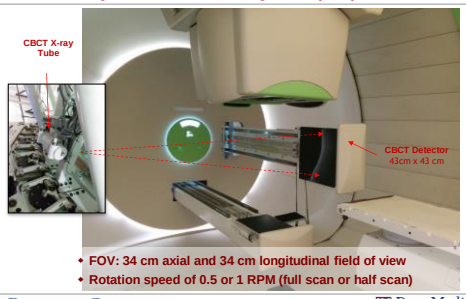
Disclosure

- **Received travel funds from IBA in 2015.**

The Rational for CBCT in Proton Therapy

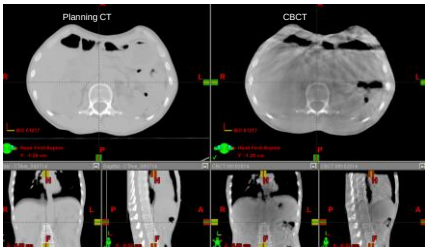
- **All the advantages of CBCT in photon therapy:**
  - Visualization of soft tissue
  - 3D anatomy matching/patient alignment
  - Assessment of tumor size or location
  - Trigger for Adaptive therapy

Gantry Mounted CBCT System (IBA)

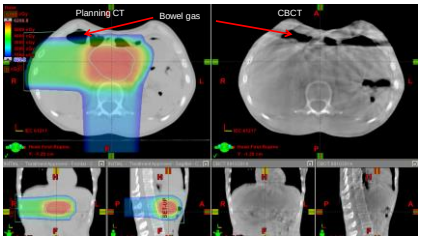


- FOV: 34 cm axial and 34 cm longitudinal field of view
- Rotation speed of 0.5 or 1 RPM (full scan or half scan)

Clinical Example- Pelvis



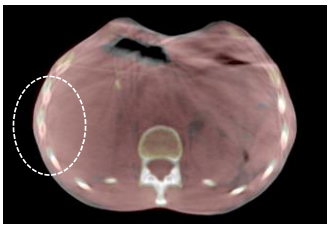
Assessment of Changes in Beam Path



Potential impact of bowel gas along beam path

Qualitative Assessment- Setup

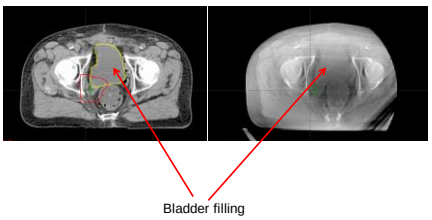
Rib position



CBCT and CT blended image after orthogonal X-ray setup

CBCT allows for more comprehensive assessment of 3D positioning

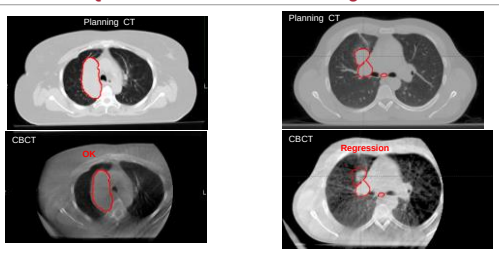
Assessment of Daily Organ Filling



Bladder filling

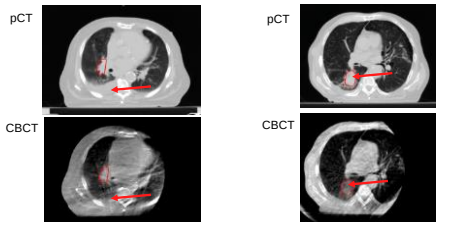
Verification of target position prior to treatment

Qualitative Assessment of Lung CBCT



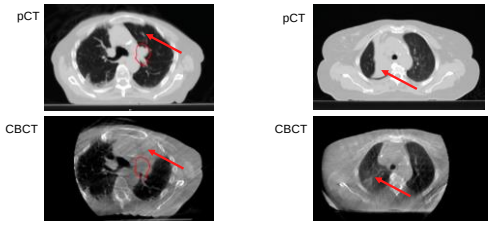
Identification of anatomical change and soft tissue target localization

Complex Anatomical Change



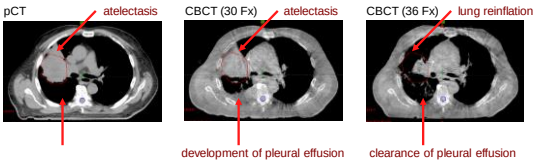
Pleural effusion **Tumor density change**

Other Types of Anatomical Change



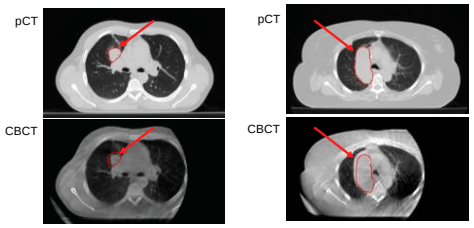
Atelectasis **Lung reinflation**

Dynamics of Pleural Effusion and Atelectasis



Anatomical change will impact proton range, periodic assessment during treatment is necessary

Beyond Qualitative Assessment



Tumor regression **Tumor growth**

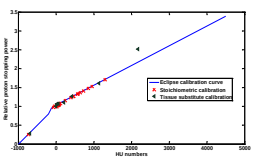
Impact on dose distribution to target and organs at risk needs to be assessed

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**

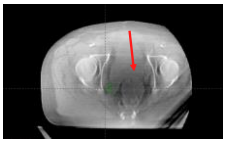


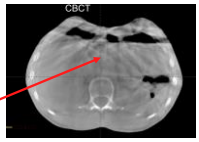
If CT number is off by 100 HU
Stopping power is different by 5%
For a 10cm range, error is 5 mm.

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)**

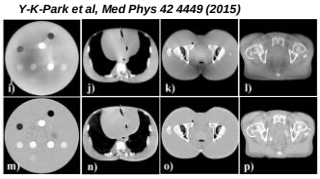




- **Motion artifacts (streaking)**

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**
   Y-K-Park et al, Med Phys 42 4449 (2015)

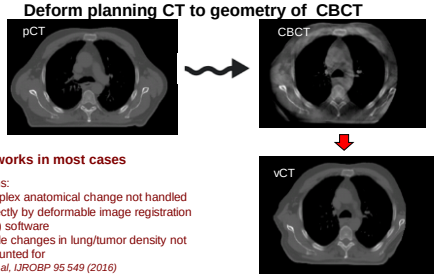


CBCT with uniform scatter correction

CBCT with *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

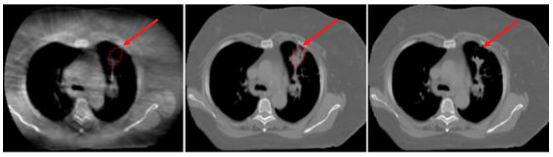
Limitations:
(1) Complex anatomical change not handled correctly by deformable image registration (DIR) software
(2) Subtle changes in lung/tumor density not accounted for

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

CBCT vCT Corrected vCT



Large tumor regression

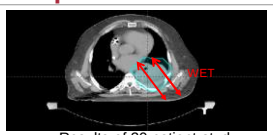
Correction for Lung Changes

Atelectasis: Not handled correctly by deformable image registration

CBCT vCT Corrected vCT

Lung reinflation

Comparison of Virtual CT with Rescan CT



WET:
Water Equivalent Thickness from entrance of beam to target

Results of 20 patient study:

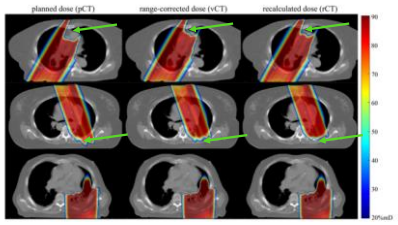
Region of interest	WET_{mean} (mm)	WET_{RMS} (mm)	$WET_{95\%}$ (mm)
Distal surface	0.5±2.2	3.7±1.9	8±4
Proximal surface	0.1±1.9	2.3±1.5	4±3
PTV	0.4±2.1	3.4±2.0	7±4

- Mean difference in WET is about 1mm
- 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



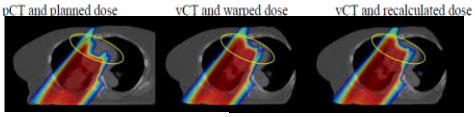
Over-ranging

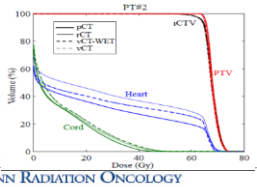
Under-ranging

No Change

C Veiga et al, IJROBP 95 549 (2016)

Traditional Analysis with vCT





Feasible to replace evaluation CTs with CBCT

IJROBP Veiga et al 2016

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**