CBCT: Past, Present and Future

Douglas Moseley PhD, DABR

Disclosures

- License Agreement Modus Medical
- Educational Consultant Elekta Oncology Systems

Computed Tomography

First CT Scanner

“Third Generation” CT Scanner

Sir Godfrey Hounsfield
Nobel Prize (1979)

Fan Beam X-ray Source
1-D Detector Array
Multiple Projections, P(α, t)

CT Slice

1975

Today

Siemens Medical Solutions

2007: kV Cone-Beam CT for IGRT

Varian TrueBEAM

Elekta Synergy

kV Sources for Guidance

- A.F. Holloway,
  - Brit.J.Radiol. 31: 227 (1958)
- H.E. Johns et al.,
  - Am.J.Roentgenol. 81: 4-12 (1959)
- Weissbluth et al.,
  - Radiology 72: 242-253 (1959)
- L.M. Shevron et al.,
  - Clin.Radiol. 17: 139-140 (1966)
- H.P. Culbert et al.,
  - UROBP 10 Sup 2: 180 (1984)
- P.J. Biggs et al.,
- R. Seghton et al.,
a-Si Flat-Panel Detectors
“digital camera for x-rays”

- Fast readout (30 fps)
- High Efficiency (DQE)
- Large FOV
- Robust (B Field, etc)
- Compact
- Distortion free

- Promising for radiography, fluoroscopy, mammography
- Ideally suited to cone-beam CT

Raw Projection Data

- 1024x1024
- Defects
- Unequal exposure

Processed Projections

- attenuation = - ln(I/I₀)
- “white” bones

“white” bones
Filtered Back-Projection

- Log & Weight
- 1D FFT-based Hamming Filter
- 4x 2D Interpolation
- Reconstruction Volume
- Geometry
- Repeat
- \# of voxels
- \# of projections

Processed Projections

- Filtered
  - ramp + hamming=1
- Appears as edge enhancement

Axial Reconstruction

\[ \Delta s \cdot \sum_{i=1}^{N} \mu_i = -\ln \frac{I}{I_0} \]

- 651 projections
- 360 deg
- 40cm x 40cm
QA for IGRT Systems

- Published AAPM reports
  - TG-58 (Portal Imaging)
  - TG-104 (Image-guidance systems)
  - TG-142 (General accelerator QA)
  - TG-148 (Tomotherapy)
  - TG-135 (Robotic Radiosurgery)
  - TG-154 (Ultrasound)
  - TG-179 (CT-based IGRT)

CBCT Image Quality Metrics

- Spatial Integrity
  - Scale, orientation, isocentricity, chirality
- Spatial Resolution
- Uniformity
- Contrast/Noise (CNR)
  - Low Contrast Detectability
- CT Number Accuracy
Spatial Resolution

Factors affecting spatial resolution:
- Focal spot size
- Detector pixel size
- Slice thickness
- Number of projections
- Reconstruction filter (kernel)
- Field of view
- Patient motion

Metrics of spatial resolution:
- Minimum resolvable line-pair
- Point-spread function (psf)
- Modulation transfer function (MTF)

Effect of Incorrect Calibration

Quantitative Assessment of CT #

Cupping: 164 to 40 HU
CBCT - Soft Tissue Visualization

Helical CT

With non-linearity/scatter corrections

Cone-beam CT

Letourneau, IJROBP 2007

Letourneau, IJROBP 2007

PMH XVI Archive (Px: 14951, Images: 400737)

ATec Education Course Feb 28-Mar3, 2017
Prostate Matching Objectives

• This continuing education exercise was developed with an aim to:
  1. Determine baseline variation for soft-tissue matches
  2. Determine expert consensus
  3. Identify cases with large inter-observer variability
  4. Identify opportunities and strategies to improve soft tissue prostate targeting among therapists to improve care to patients.

Characteristics of “Hard” GU Cases

1. Patient Preparation
   - Small Bladder
     • Deformation
   - Gas in rectum
     • Deformation
     • Streak artifacts
   - Prostate rotation

2. Patient Setup
   - Large baseline shift from bone
Standard Deviation of All Observers

- 5 experts
- 33 observers
- 16 cases
Patient 3 – Patient Setup

Bone Match

Patient 3 – Patient Setup

Prostate Match (Mean of Experts)

Patient 3 – Patient Setup

Absolute Difference
X = 0.01cm
Y = 1.14cm
Z = 0.94cm
Respiratory Motion Artifacts

CT
- Immobilize
- Fast Scanning
- Patient Preparation

Cone-Beam CT
- Retrospective Sorting
- Gating
- Tracking

---

Patient Acquisition Sequence

- 79 yr old female with cholangiocarcinoma
- Treated with 54 Gy in 6 fx using respiratory gating
- Technique
  - 120kVp, 100mA
  - 13 ms/pulse
  - ~1.2-2.0 cGy

---

Central Axial Slice

25.6 cm Axial FOV
Consistent data
Clearly see diaphragm motion
Motivation for measuring ventilation

- Changes in lung ventilation may predict radiotherapy-induced toxicities.

- 4D-CBCT limitation: Low image quality

- Approach: Improve 4D-CBCT and compare ventilation to 4D-CT

Kasper Jensen, Odense

Improvements of 4D-CBCT: Examples
CBCT derived radiosensitivity marker associated with radiation pneumonitis

Pencilla Lang*  
Douglas Moseley*  
Uffe Brinch*  
Cartsen Brink*  
Andrew Hope*

*Department of Radiation Oncology, Princess Margaret Cancer Centre  
+Institute of Clinical Research, University of Southern Denmark

Presented by: Pencilla Lang, BEng, MD, PhD

Background
No patient-specific predictors of normal lung radiosensitivity in clinical use

- Imaging features correlate with clinical pneumonitis

PET  
VQ  
CT

(Castillo et al, 2014)  
(Xiao et al, 2017)  
(Cunliffe et al, 2015)

(Castro et al, 2014)
Methods - Overview

Image Extraction

Methods - Overview

Image Extraction  Registration

Methods - Overview

Image Extraction  Registration  Analysis
Results

- Univariate logistic regression of dosimetric parameters and CBCT markers with symptomatic pneumonitis:
  - CBCTM10, MLD, V20 not significant (p > 0.05)
  - CBCTM20 significant (p < 0.01)

- Multivariate logistic regression with CBCTM20 and V20 significant for both (p < 0.05)

Review of Module Objectives

• Introduce Cone-Beam CT System Components
• a-Si Flat Panel Detectors
• Reconstruction Process
• Image Quality Metrics (AAPM TG-179)
• Confounding Patient Factors
  – Motion, Setup
IGRT Systems: Ideal Properties

- Accurate, precise
  - Explicit interpretation
  - Minimal training, operator independent
- Efficient, integrated
  - Rapid
  - Integrated with machine for remote intervention
  - Low impact on resources
- Broad/Universal application
  - Large number of anatomical sites
  - Large field of view
- Reduce radiation dose
  - Non ionizing, or efficient detectors
  - Account for imaging dose?
- Real-time
  - Continuous monitoring
- Images for planning & evaluation
- CHEAP!


Acknowledgements

- Pencilla Lang, Winnie Li, Jean-Pierre Bissonnette, Daniel Létourneau, David Jaffray
- NKI – Jan-Jakob Sonke,
- Christy - Marcel van Herk
- JHU – Jeff Siewerdsen
- Odense – Kasper Jensen, Carsten Brink, Uffe Bernhoul