In-Room Radiographic Imaging for Localization

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Outlines of the Talk

- Introduction
- Imaging Method
- Clinical Applications
- Special Considerations
- Summary
Why In-Room – Prostate IMRT Case
Why In-Room: H&N Case
Why In-Room: Improving Precision and Accuracy

Accurate but not precise: IGRT

Precise but not accurate: IMRT

Precise and accurate: IGRT+IMRT

Yin et al. Sem Rad Onc 2006
Imaging Methods

- Film Imaging
- Computed Radiography Imaging
- Digital MV X-ray Imaging
- Digital kV X-ray Imaging
  - Room-Mounted System
  - Gantry-Mounted System
  - Mobile Systems
- Tomographic Imaging
  - On-board CBCT
  - On-board Digital Tomosynthesis (DTS)
**Imaging Method: Film Imaging**

**Imaging principle**

- **Metal sheet** → produce electrons
- **Screen** → convert to light
- **Film** → image

**H&D Curve**
Examples of Film Imaging Systems

The Kodak EC-L film system
EC film + Kodak EC-L oncology cassette (or a Kodak EC-L fast cassette)

The Kodak simulation film system
Kodak simulation film and Kodak Lanex regular screens (green sensitive)

Kodak EC-V Verification System for Portal Imaging
Kodak EC film or Kodak EC-V verification cassette

Kodak Portal Pack for Localization Imaging
READY-PACK Packaging with or without a metal screen cassette

Kodak X-OMAT V Film and Cassettes
Used for verification imaging and dosimetry testing

Kodak EDR2 Film
READY-PACK Packaging

## Examples of Film Imaging Systems

<table>
<thead>
<tr>
<th>FILM</th>
<th>RESPONSE RANGE</th>
<th>APPROXIMATE SATURATION EXPOSURE</th>
</tr>
</thead>
<tbody>
<tr>
<td>KODAK Portal Pack for Localization Imaging (PPL)</td>
<td>0.25 - 5 cGy</td>
<td>10 cGy</td>
</tr>
<tr>
<td>KODAK X-OMAT V Film (XV-2)</td>
<td>5 - 100 cGy</td>
<td>200 cGy</td>
</tr>
<tr>
<td>KODAK Extended Dose Range Film (EDR2)</td>
<td>25 - 400 cGy</td>
<td>700 cGy</td>
</tr>
</tbody>
</table>

[Link to Kodak products page](http://www.kodak.com/global/en/health/productsByType/onco/onco_Product.jhtml#products)
Imaging Method: CR Imaging

CR imaging principle
Imaging Method: CR Imaging

CR - kV simulation image

CR - MV portal image
Digital MV X-ray Imaging

• Camera and scintillation screen based imagers
  – Incident x-rays interact with a metal plate and scintillation screen to produce visible light.

• Liquid ionization chamber system
  – the ionization behavior of the liquid and the performance of the readout electronics

• Amorphous Silicon (a-Si) technology
Digital kV X-ray Imaging

- Digital kV X-ray Imaging
  - Room-Mounted System
  - Gantry-Mounted System
  - Mobile Systems

- Amorphous Silicon (a-Si) technology
a-Si Detector Configuration

MV imaging

kV imaging

Protection layer

Metal buildup layer

Phosphor

A-Si photodiode/TFT array

Support base

Protection layer

Anti-scatter grid

Phosphor

A-Si photodiode/TFT array

Support base
Room-Mounted X-Ray Systems

CyberKnife® imaging system  Novalis® imaging system
Gantry-Mounted X-Ray Systems

Elekta Synergy® system

Varian Trilogy™ system
“Mobile” Systems

Varian ExaCT™ at MDACC

Siemens C-arm system
MV Tomographic Imaging

TomoTherapy Unit

Siemens’ system
Radiographic Imaging Options

Orthogonal radiograph

Cone-Beam CT (CBCT)

DTS - Digital TomoSynthesis

Patient

Patient

Patient

DRR

kV image

CT

CBCT

RDTS

DTS
On-Board kV and MV Radiographs

2-D kV radiographs

2-D MV radiographs

kV compared to MV:
- Better bone/soft tissue contrast
- Less radiation dose
- No metal artifacts
- Fluoroscopic imaging
- Not treatment beam
- Not real-time imaging
Tomographic Imaging: On-board Cone-Beam CT (CBCT)
On-Board H & N DTS Imaging

0°

DRR
MV rad
kV rad

44°

RDTS
DTS

360°

CT
CBCT

Godfrey, Yin et al
Red J May 2006

Godfrey, Yin et al
Red J May 2006
On-Board Prostate DTS Imaging

0°

0° DRR MV rad kV rad

44°

44° RDTS DTS

360°

360° CT CBCT

Godfrey, Yin et al
Red J May 2006
On-Board Liver DTS Imaging

0°
- DRR
- MV rad
- kV rad

44°
- RDTS
- DTS

360°
- CT
- CBCT

Godfrey, Yin et al
Red J May 2006
Clinical Applications

• Off-line Correction
  – Portal Verification
  – Isocenter Verification

• On-line Correction
  – kV-kV Localization
  – kV-MV Localization
  – MV-MV Localization
  – CBCT-Guided Localization
  – Image Fusion

• Imaging for Respiratory-gated Treatment
Off-Line Portal Verification

- Compare
- Next tx
- Reference images
- Patient setup
- Treatment
- On-board images
What Will Off-Line Verification Do for Precision and Accuracy?

Random error  
Systematic error  
Systematic & Random error
Portal Field Verification

Reference image

Portal image
Portal Field Verification

Reference image

Portal image
Portal Field Verification

Reference image

Portal image
Isocenter Verification (MV/MV)

Reference image

Portal image
Isocenter Verification (kV/kV)
On-Board CBCT for Soft Tissue
On-Line Portal Verification

Patient setup

On-board images

Reference images

Correction?

Feedback

Treatment

Shift couch

On-board images

On-board images
What Will On-Line Verification Do for Precision and Accuracy?

Random error

Systematic error

Systematic & Random error
On-Line Localization – MV/MV

Before beam-on

After treatment
On-Line Localization kV/kV
On-Line Localization - kV/MV

Couch Shift (VARR_IEC Scale, all units in cm and degrees)

<table>
<thead>
<tr>
<th>Raw Shift Values</th>
<th>SHIFT</th>
<th>SHIFT</th>
<th>Machine Values</th>
<th>TARGET</th>
<th>ACTUAL</th>
<th>SHIFT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Couch Lat</td>
<td>0.0</td>
<td></td>
<td>Couch Lat</td>
<td>999.4</td>
<td>999.4</td>
<td>0.0</td>
</tr>
<tr>
<td>Couch Long</td>
<td>0.0</td>
<td></td>
<td>Couch Long</td>
<td>76.0</td>
<td>76.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Couch Vert</td>
<td>0.0</td>
<td></td>
<td>Couch Vert</td>
<td>13.0</td>
<td>13.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Couch Proj Rtn</td>
<td>0.0</td>
<td></td>
<td>Couch Rtn</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Couch Rtn</td>
<td>0.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

[Reset Shift] [Apply Shift]
Planning CT and On-Board CBCT
Image Fusion

• Manual
  – Skill and knowledge: always needed

• Automatic
  – Control-point fusion
  – Edge-based fusion
  – Moment-based fusion
  – Mutual information/correlation based fusion

• Rigid and non-rigid (deformable)
Image Fusion – 2D to 3D

Planning CT

Updated $\theta$, $\Phi$, $\Psi$, $\delta x$, $\delta y$, $\delta z$

New DRR

Calculate Correlation Coefficient and Mutual Information

Criteria for stopping loop

Shift and Rotation

OBI Images
Image Fusion – 2D to 3D

- Shift and Rotation
- Rigid body 3-D to 2-D
- Iterative DRRs
- Different shift and angulations
- Mutual image information
Image Fusion – 3D to 3D

New ref. CT

Planning CT

Updated $\theta, \Phi, \Psi, \delta x, \delta y, \delta z$

Calculate Correlation Coefficient and Mutual Information

Criteria for stopping loop

Shift and Rotation
Image Fusion – 3D to 3D

Target

CBCT match to Sim-CT

Sim-CT
Imaging for Respiratory-Gated Treatment

• Anatomical imaging
  – Breath-hold
  – Gated treatment
  – Real-time portal verification

• Dosimetric imaging
  – Intensity map
4-D Fluoroscopic Imaging

Markers

Gated Treatment
Breath-Hold Treatment Localization

DRR (breath-hold)  kV (free-breathing)  kV (breath-hold)
Breath-Hold CBCT and Treatment

Yin et al, Sem Rad Onc 2006

Sim CT
Free-breathing
Breath hold

CBCT
Breath-Hold Digital Tomosynthesis
Breath Real-Time Portal Verification

20 portal images in cine mode with < 1 s interval
Liver - Effect of Breath-Hold
On-Board Breath-Hold for Liver

breath-hold RDTS

breath-hold DTS
Special Considerations

- Treatment Time with Corrective Action
- Quality Assurance
- Imaging Dose
- Other Considerations
## Dose/Exposure vs Imaging Modality

<table>
<thead>
<tr>
<th>Modality</th>
<th>Dose/Exposure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Orthogonal set of MV digital images (Kutcher et al. 1994)</td>
<td>5–8 cGy</td>
</tr>
<tr>
<td>Orthogonal set of KV images</td>
<td>&lt;0.1 cGy</td>
</tr>
<tr>
<td>CBCT Body scan (Fritsch et al. 1995; Yoshizumi et al. 2006)</td>
<td>3–4 cGy</td>
</tr>
<tr>
<td>CBCT Head scan (Yoshizumi et al. 2006)</td>
<td>8 cGy</td>
</tr>
<tr>
<td>MVCT of Tomotherapy (Sheng et al. 2005)</td>
<td>1 cGy</td>
</tr>
<tr>
<td>CT simulation scan (Judy et al. 1977)</td>
<td>3–4 rads</td>
</tr>
</tbody>
</table>
QA for OBI/CBCT

- **Safety and functionality**
  - Door interlock, collision interlock, beam-on sound, beam-on lights, Hand pendant control, and network-flow.
  - All test items are verified during tube warm-up (< 5 min)

- **Geometric accuracy**
  - OBI isocenter accuracy
  - Accuracy of performance for 2D2D match and couch shift
  - Mechanical accuracy (arm positioning of KVS and KVD)
  - Isocenter accuracy over gantry rotation

- **Image quality**
  - OBI (radiography): contrast resolution and spatial resolution
  - CBCT (tomography): HU reproducibility, contrast resolution, spatial resolution, HU uniformity, spatial linearity, and slice thickness.
# Total Treatment Time for IGRT

<table>
<thead>
<tr>
<th>Activity</th>
<th>Time (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patient setup in the room</td>
<td>2 – 5</td>
</tr>
<tr>
<td>OBI kV/kV or MV/kV imaging</td>
<td>~ 1</td>
</tr>
<tr>
<td>2D2D matching analysis</td>
<td>2 – 5</td>
</tr>
<tr>
<td>CBCT imaging</td>
<td>3</td>
</tr>
<tr>
<td>3D3D matching analysis</td>
<td>2 – 5</td>
</tr>
<tr>
<td>Re-positioning</td>
<td>~ 1</td>
</tr>
<tr>
<td>Treatment delivery</td>
<td>10 – 15</td>
</tr>
<tr>
<td>Total treatment time for IGRT with CBCT</td>
<td>20 – 35</td>
</tr>
<tr>
<td>Total treatment time for IGRT without CBCT</td>
<td>15 – 25</td>
</tr>
</tbody>
</table>
Other Considerations

- Hardware
- Software
- Network
- Power
- Financial
- Training
- Staffing
- Billing
Information Management: Departmental Integration

- Simulation
- Planning
- Consultation
- Treatment
- Follow-up

- Computation (Seconds, minutes?)
- Speed (Seconds?)
- Accessibility (Anywhere?)
- Quality assurance (Pre-, on-line? after?)
What Does IGRT Really Mean?

- Patient data
- Image data
- Clinical data

OIS

Reasoning

Information-Guided Radiation Therapy
Planned Duke IGRT-2006

- Duke Rad Onc Thinking Engine
- Duke RIS/HIS
- Electronic Presentation
- ARIA
- IGS
- SRS Unit
- CR
- Backup system
- JMH
- DRH
- DHRH
- VAMC
- MPH
On-Board kV and MV CBCT: Effect of Metal Artifact and Blurring

- MV CBCT with metal ball
- kV CBCT with metal ball
- kV CBCT no metal ball

Metal ball
On-Board kV and MV DTS: Effect of Metal Artifact and Blurring

Zhang, Yin 2006 AAPM
kV/MV Dual Beam CBCT Images

Yin et al. Med Phys 2005
3-D Dose and Anatomy Verification

27:1406 (AAPM 2000)
On-Board CBCT/SPECT Imaging

Bowsher, Yin et al,
AAPM/ASTRO 2006

0.35 mCi Tc-99m line-sources

Flat-Panel Detector  Anger Camera

Bowsher, Yin et al,
AAPM/ASTRO 2006
Summary

• In-room radiographic imaging is aimed to reduce margin from CTV to PTV

• It is one component of IGRT

• Patient information management is critical for modern radiation therapy

• New challenges are emerging from better in-room imaging
An Example of IGRT Application
IGRT Case: CBCT-Guided SBRT

Case selection

Immobilization

4-D simulation

4-D Planning

2-D kV/MV imaging

2/3-D imaging

Treatment

2/3-D imaging

CBCT vs. Sim Comparison

CBCT imaging

Yin et al ASTRO 2006
Para-spinal Case

- **Diagnosis**
  - Paraspinal lung met (previously treated)

- **GTV = 12 cc**

- **PTV = GTV + 5 mm (37.3 cc)**

- **Prescription:**
  - 10 Gy x 3 fractions
  - ~95% to iso

- **6 co-planar IMRT fields (6X,15X)**
Para-spine - Immobilization

Setup Pictures
Treatment Volume
Iso-Dose Distribution
Planning Results

Absolute Dose (cGy)
Pre-Treatment CBCT Localization

CBCT matching planning CT
Treatment Accuracy

After CBCT and planning CT matching and patient shifting
Fusing of planning CT and CBCT after treatment
Treatment Follow-Up

Aug 2005 PET/CT

Nov 2005 PET/CT

Jan 2006 PET/CT
Residual Errors between Pre- and Post-Treatment
Residual Error between 2-D Imaging and CBCT
Thanks
IGRT – An Integrated Process

Oncology Information System (OIS)

- Scheduling
- Tx Evaluation
- Patient Information
- Planning and Prescription
- QA
- Clinical Evaluation
- Imaging & Sim
- Treatment
- Record & Verify