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
- Precise but not accurate
- Precise and accurate

IMRT
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
- H&D Curve
- Metal sheet ➔ produce electrons
- Screen ➔ convert to light
- Film ➔ Image
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 sensitives)

- 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 Cassette
  Used for verification imaging and dosimetry testing

- Kodak EDR2 Film
  READY-PACK Packaging


Imaging Method: CR Imaging

- CR imaging principle
  CR for sim., loc., verl.

- CR - kV simulation image

- CR - MV portal image


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</td>
<td>0.25 - 8 cGy</td>
<td>15 cGy</td>
</tr>
<tr>
<td>KODAK X-OMAT V Film (EK-2)</td>
<td>0 - 185 cGy</td>
<td>200 cGy</td>
</tr>
<tr>
<td>KODAK Extended Dose Range Film (EDR2)</td>
<td>25 - 420 cGy</td>
<td>700 cGy</td>
</tr>
</tbody>
</table>

**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

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**a-Si Detector Configuration**

- Protection layer
- Metal build-up layer
- Anti-scatter grid
- Phosphor
- A-Si photodiode/TFT array
- Support base

**Room-Mounted X-Ray Systems**

- MV imaging
- kV imaging

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

Duke On-Board Imager (OBI)

- KV source (KVS)
- KV detector (KVD)
- Portal imager (EPID, MVD)
- Clinac
- OBI
- 4DTC
- RPM
Radiographic Imaging Options

- Orthogonal radiograph
- Cone-Beam CT (CBCT)
- DTS - Digital TomoSynthesis

On-Board kV and MV Radiographs

- 2-D kV radiographs
- 2-D MV radiographs

Tomographic Imaging:
On-board Cone-Beam CT (CBCT)

- CT
- CBCT

On-Board H & N DTS Imaging

- 0°
- 44°
- 360°

- DRR
- MV rad
- kV rad
- DTS
- CBCT

kV compared to MV:
- Better bone/soft tissue contrast
- Less radiation dose
- No metal artifacts
- Fluoroscopic imaging
- Not treatment beam
- Not real-time imaging

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
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
Isocenter Verification (MV/MV)

Reference image  Portal image

Isocenter Verification (kV/kV)

On-Board CBCT for Soft Tissue

Reference image  Portal image

On-Line Portal Verification

Patient setup  Reference images

On-board 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
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**

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

- **Planning CT**
  - New ref. CT
  - Calculate Correlation Coefficient and Mutual Information
- **On-board CBCT**
  - Updated $\theta, \phi, \psi, \delta x, \delta y, \delta z$
  - Criteria for stopping loop
  - YES
  - NO
  - Shift and Rotation

**Target**

**Sim-CT**

**CBCT match to Sim-CT**

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**Imaging for Respiratory-Gated Treatment**

- **Anatomical imaging**
  - Breath-hold
  - Gated treatment
  - Real-time portal verification
- **Dosimetric imaging**
  - Intensity map

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**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

**Breath-Hold Digital Tomosynthesis**

- RDTS
- DTS

**Breath Real-Time Portal Verification**

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

Free-Breath ITV Verification with CBCT

On-Board Breath-Hold for Liver

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</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 (Steer et al. 2005)</td>
<td>1 cGy</td>
</tr>
<tr>
<td>CT simulation scan (Judy et al. 1997)</td>
<td>3-4 mrad</td>
</tr>
</tbody>
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### 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.

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### 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>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

Planning Images

CT images: 0.514 MB/image
MR images: 0.188 MB/image
PET images: 0.034 MB/image

Localization Images

- kV image: 1.54 MB (1024x768x2)
- MV image: 0.386 MB (512x384x2)
- DRR image: 0.514 MB (512x512x2)
- CBCT images: 28 MB (55 x 0.512 MB)

Storage Requirements

Typical CT-based plan size: 50-200 MB

Typical IGRT patient fold size: 600MB-2GB

> 95% images:
Planning images including CT, MR, PET/CT, gated 4-D images, breath-hold CT
Verification images including: kV, MV, CBCT, cine, etc
Information Management: Departmental Integration

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

What Does IGRT Really Mean?

- Patient data
- Image data
- Clinical data

Planned Duke IGRT-2006

- Duke RIS/HIS
- Electronic Presentation

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

Dose Comparison: CT vs CBCT

3-D Dose and Anatomy Verification

Brain (6 MV) Lung (6 MV) Prostate (15 MV)
On-Board CBCT/SPECT Imaging

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 → 2/3-D imaging
Immobilization → Treatment
4-D simulation → 2/3-D imaging
4-D Planning → CBCT vs. Sim Comparison
2-D kV/MV imaging → CBCT imaging

Bowsher, Yin et al, AAPM/ASTRO 2006

Yin et al ASTRO 2006
Para-spi nal 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-spi ne - Immobilizati on

Setup Pictures

Treatment Volume

Beam Design
Iso-Dose Distribution

Planning Results
Absolute Dose (cGy)

Cord
Lung
P TV
G TV

Pre-Treatment CBCT Localization
CBCT matching planning CT

Treatment Accuracy
Reference After treatment Before treatment
After CBCT and planning CT matching and patient shifting
Thanks