What Imaging Aspects Should a Radiotherapy Physicist know Today?
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Introduction

• Increase imaging use in radiation therapy
• Imaging aspects key in radiation therapy
  – Geometric Accuracy
  – Image Quality
• Radiation Dose from Imaging
• Resources available on Imaging Physics
X-ray based Imaging Modalities in RT

- Radiography
  - Portal Imaging
  - Cyberknife
- Fluoroscopy
- Computed Tomography (CT)
  - CT-on-rails
  - 4D CT
  - kV-CBCT
  - MV-CBCT

kV-CBCT integrated with LINAC

- Rapidly implemented imaging modality in RT
- High-spatial resolution
- kV-CBCT tube and detector are mounted on same gantry as LINAC treatment head

Imaging in Cyberknife setup

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Essential Aspects of Imaging

- Balance between increased imaging and improved therapeutic dose conformity
- Image quality and radiation dose are intertwined (two sides of same coin)

Imaging Phases in Cancer Patients

- Prior
  - CT
  - Radiograph
  - Fluoroscopy
  - PET-CT
  - Ultrasound
  - MRI
- During
  - DRR
  - Portal
  - EPI
  - CT Simulator
  - CBCT
  - 4DCT
- Post
  - CT
  - PET-CT
  - Radiograph

Imaging Phases in Cancer Patients
Case 1 - Head & Neck: June 2011 - Sept 2012

- Prior
  - PET-CT – 6
  - H&N – 3
  - CAP – 3
  - CT – 6
  - H&N – 3
  - Chest – 2
  - Abdom & Pelvis – 1
  - Radiographs
  - CXR – 2
  - Fluoroscopy – 2
  - MRI – 1
- During
  - DRR – 4
  - Portal – 2
  - CT – 2
- Post
  - ?
Imaging Phases in Cancer Patients
Case 2 - Pediatrics: 2007-2010

Prior
- CT - 6
- H&N - 3
- Chest CT - 2
- Abd & Pelvis - 1
- Radiographs
- CR - 5
- Extremities - 6
- Fluoroscopy - 3
- MRI - 2
- Ultrasound - 4

During
- DRR - 2
- EPI - 3

Post
?

Johns Hopkins Data

Radiation Dose from Imaging in Therapy

• Managing imaging dose in RT is different than in diagnostic imaging
• Imaging dose has been regarded as negligible and has been quantified in fairly looser manner
Should we be concerned about radiation doses from imaging during radiation therapy?

- **Maybe**
  - Depends on the patient’s age, imaging type
- **Yes**
  - Pediatric and Younger patients
- **No**
  - Imaging doses are decreasing due to technological advances, awareness and better patient selection

Number of CT procedures in US

<table>
<thead>
<tr>
<th>Year</th>
<th>CT procedures (millions)</th>
</tr>
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<tbody>
<tr>
<td>2007</td>
<td>68.7 million</td>
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<tr>
<td>2008</td>
<td>73.1 million</td>
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<tr>
<td>2009</td>
<td>77.5 million</td>
</tr>
<tr>
<td>2010</td>
<td>81.9 million</td>
</tr>
<tr>
<td>2011</td>
<td>85.3 million</td>
</tr>
<tr>
<td>2012</td>
<td>80.6 million</td>
</tr>
<tr>
<td>2013</td>
<td>76.0 million</td>
</tr>
</tbody>
</table>

OECD CT data as of 2011*

<table>
<thead>
<tr>
<th>Country</th>
<th>CT Scanners per million population</th>
<th>CT exams per 1000 population</th>
</tr>
</thead>
<tbody>
<tr>
<td>US</td>
<td></td>
<td></td>
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<tr>
<td>Japan</td>
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</tbody>
</table>

*Organization of Economic Co-operation and Development (OECD) Health Data 2013
Radiation exposure to US population:

- US 1982 (NCRP 93):
  - Medical: 0.54 mSv per capita
  - Total: 3.6 mSv per capita

- US 2006 (NCRP 160):
  - Medical: 3.0 mSv per capita
  - Total: 6.2 mSv per capita

NCRP 160 published March 2009

Global annual per-capita effective radiation dose from various sources:

- 1980-1984:
  - Medical: 15%
  - Background: 83%
  - Consumer products: 2%
  - Occupation: 0.3%
  - Natural: 50%
  - CT: 24%
  - Nuclear Medicine: 13%
  - Radiography: 5%
  - Interventional: 6%
  - Other: 3%

- 1997-2007:

Mettler FA et al. Radiology 2009;253:520-531

Research protocols with multiple CT scans:

- How many provides useful information?

Radiation dose from CT scans: HCAP ~20 mSv per visit
- Total effective dose*: >100 mSv in less than 200 days

* Including 4 bone scans @ 7 mSv per scan
Differences in Organ Dose Distribution

- **Diagnostic Imaging**
  - All organs in field of view are exposed
  - Effective dose (mSv) – risk to whole body from exposure to certain region

- **Radiation Therapy**
  - Organ doses (mGy) confined to region of interest
  - Surrounding organs protected to large extent

Quality Assurance

Quality Assurance for Imaging in Therapy

- Image quality requirements for QA differ
- Primary aim of image guidance is to detect and correct positional uncertainties, hence geometric accuracy assessment is key
- Tolerance and frequency of testing should be based on intended use of images

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Quality Control of CT Scanners

ACR CT Phantom®

CT Number Calibration
- CT Numbers for all materials can vary somewhat depending on system’s x-ray beam spectra, beam hardening and scatter
- Phantom of known CT numbers scanned to determine accuracy

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Low contrast resolution object and image

PET-CT in Radiation Therapy

PET-CT Scanner

CT Gantry

PET Gantry

Table

CT Scan Plane

PET Scan Plane
PET-CT Alignment

- Most crucial QC
- Spatial co-registration between CT and PET scanners

ACR/Jaszczak Phantom

MRI in Radiation Therapy

MR Facility Zone Configuration

- Zone I
  - Areas freely accessible to public
- Zone II
  - Interface between public accessible, uncontrolled Zone I and strictly controlled Zone III
- Zone III
  - Free access by unscreened non-MR personnel or ferromagnetic objects can result in serious injury or death
- Zone IV
  - MR Scanner magnet room

AJR: 188, June 2007
MR Quality Control Tests

- Homogeneity of Magnetic Field
- Geometric Accuracy
- High-Contrast Spatial Resolution
- Slice Thickness Accuracy
- Slice Position Accuracy
- Image Intensity Uniformity
- Percent-Signal Ghosting
- Low-Contrast Object Detectability

ACR MRI Accreditation Phantom

www.acr.org

PET-MRI
Imaging Resources for Therapy Physicists

RSNA website

- Available free for RSNA and AAPM members
- More than 30 manuscripts currently available in RadioGraphics
- Search for RSNA/AAPM Physics Tutorials
- Search for RSNA Online Physics Modules
  - [https://www.rsna.org/RSNA/AAPM_Online_Physics_Modules.aspx](https://www.rsna.org/RSNA/AAPM_Online_Physics_Modules.aspx)

Physics articles are among the most-cited articles in RadioGraphics
Journal of American College of Radiology

- Most widely read journal by Radiologists
- Monthly physics columns
  - Technology Talk
  - The Medical Physics Consult
- Short focused articles on medical physics related topics

http://www.jacr.org/

JACR: Technology Talk

- Feature Editor writes and hosts others’ articles about capabilities of new technology and the safe, efficacious practice of radiology

http://www.jacr.org/content/technology_talk

JACR: The Medical Physics Consult

- Edited by Drs. Mahesh and Morin
- Medical Physicists ask and answer questions of topical importance

http://www.jacr.org/content/medical_physics
Conclusion

• Convergence of imaging and radiation therapy highlights need for convergence among therapy and diagnostic physicists
• Image quality and radiation dose are intertwined (two sides of same coin)
• Understanding various aspects of imaging is essential for high level of conformity in radiation therapy treatment