What Imaging Aspects Should a Radiotherapy Physicist know Today?

Mahadevappa Mahesh, MS, PhD, FAAPM, FACR, FACMP, FSCCT.

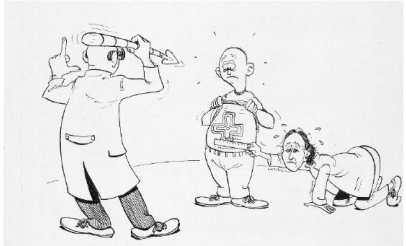
Associate Professor of Radiology and Cardiology
Johns Hopkins School of Medicine
Chief Physicist – Johns Hopkins Hospital
Baltimore, MD

56th Annual Meeting of AAPM, July 20-24, 2014, Austin, TX
Contact Info: email - mmahesh@jhmi.edu Phone: 410-955-5115 (O)

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

Image-Guided Radiation Therapy (IGRT) concept



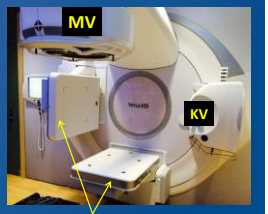
* Sandra Vieira, "Dosimetric Verification of Intensity Modulated Radiotherapy with an Electronic Portal Imaging Device". Thesis, 2005. (drawn by Andy Bahnert)

X-ray based Imaging Modalities in RT

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

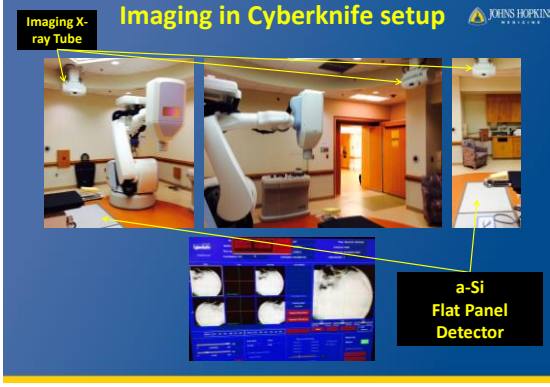
kV-CBCT integrated with LINAC

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



Flat Panel Detectors

Imaging in Cyberknife setup

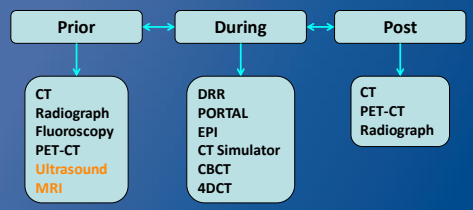


Johns Hopkins mmahesh@jhmi.edu

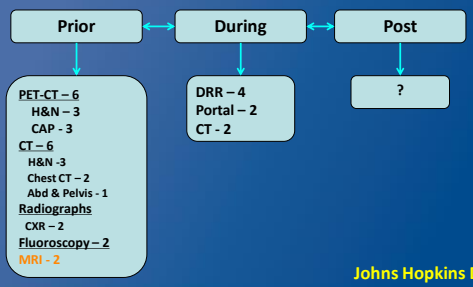
Essential Aspects of Imaging

- 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



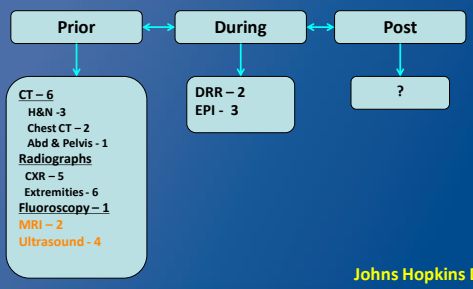
Imaging Phases in Cancer Patients
Case 1 - Head & Neck: June 2011- Sept 2012



Johns Hopkins Data

Johns Hopkins mmahesh@jhmi.edu

Imaging Phases in Cancer Patients
Case 2 - Pediatrics: 2007-2010



Johns Hopkins Data

Radiation Dose from Imaging in Therapy

Radiation Dose from Imaging

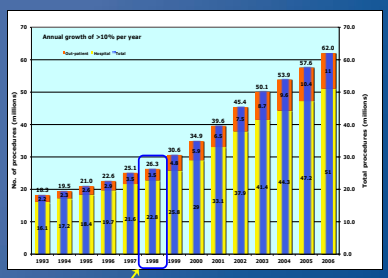
- Managing imaging dose in RT is different than in diagnostic imaging
- Imaging dose has been regarded as negligible and has been quantified in fairly looser manner

Johns Hopkins mmahesh@jhmi.edu

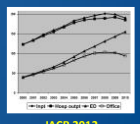
Should we be concerned about radiation doses from imaging during radiation therapy?

- 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



MDCT

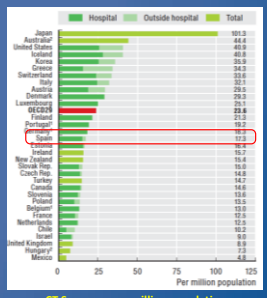


JACR 2012

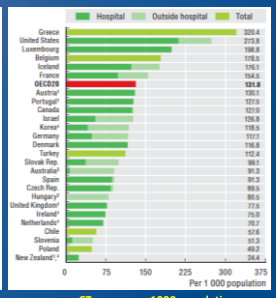
2007: 68.7 million
2008: 73.1 million
2009: 77.5 million
2010: 81.9 million
2011: 85.3 million
2012: 80.6 million
2013: 76.0 million

IMV Benchmark Reports on CT

OECD CT data as of 2011*



CT Scanners per million population



CT exams per 1000 population

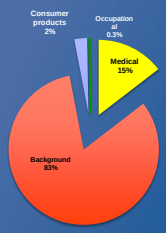
*Organization of Economic Co-operation and Development (OECD) Health Data 2013

Johns Hopkins mmahesh@jhmi.edu

Radiation exposure to US population

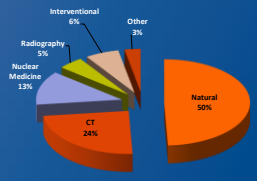
JOHNS HOPKINS MEDICINE

US 1982 (NCRP 93)



Medical 0.54 mSv per capita
Total 3.6 mSv per capita

US 2006 (NCRP 160)

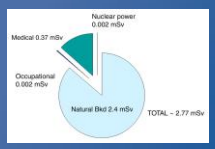


Medical 3.0 mSv per capita
Total 6.2 mSv per capita

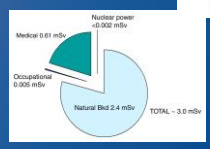
NCRP 160 published March 2009

Global annual per-capita effective radiation dose from various sources

JOHNS HOPKINS MEDICINE



1980-1984



1997-2007

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

Research protocols with multiple CT scans How many provides useful information?

JOHNS HOPKINS MEDICINE

Table 1: Time and Events Schedule

Period	Screening	Treatment									Follow-up	
		Cycle 1					Cycles 2-12					
Visit Name	Screening	C1d1	C1d2	C1d3	C1d4	C1d5	Cxd1	Cxd2	Cxd3	Cxd4	Cxd5	Follow-up 1	Follow-up 2-6
Timepoint Per Cycle (Day)	-28 to -1	1[1]	15[2]	29[3]	43[1]	50[2]	1[3]	15[2]	29[3]	43[1]	50[2]	Last Cxd5 Visit + 1 to 7 Days	Previous Follow-up Visit + 56 Days[4]
Complete physical exam[17]	•						•					•	
Pregnancy test[20]	•	•	•	•	•		•	•	•	•		•	[21]
Chest radiograph	•											•	
ECG (12-lead)	[21]						•						
CT/MRI (brain)[22,24]	[21]					[23]					[23]		[21]
CT/MRI (chest, abdomen, pelvis)[24]	[21]					[2]					[2]		•
Bone scan[25]	[21]					[2]					[2]		•

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

Johns Hopkins mmahesh@jhmi.edu

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

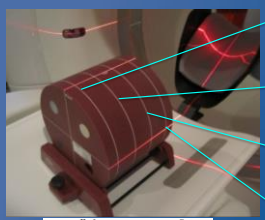
Quality Assurance for Imaging in Therapy

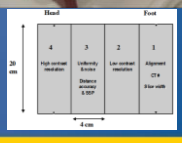
- Image quality requirements for QA differ
- Primary aim of image guidance is to detect and correct positional uncertainties, hence geometric accuracy assessment is key
- Tolerance and frequency of testing should be based on intended use of images

© Dr M. Mahesh – MS, PhD, FAAPM, FACR, FACMP, FSCCT
Johns Hopkins mmahesh@jhmi.edu

Quality Control of CT Scanners

ACR CT Phantom®

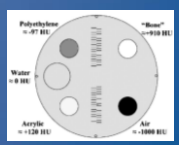


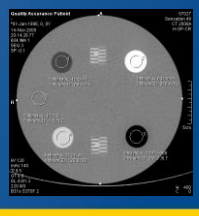


www.acr.org

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

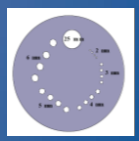




Johns Hopkins mmahesh@jhmi.edu

Low contrast resolution object and image

ACR CT Phantom



Low contrast resolution module

Low contrast resolution image

PET-CT in Radiation Therapy

PET-CT Scanner

CT Gantry

PET Gantry

Table

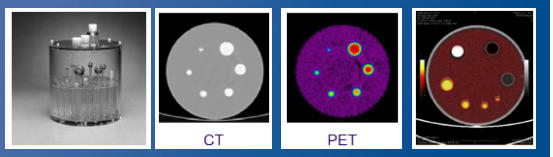
CT Scan Plane

PET Scan Plane

Johns Hopkins mmahesh@jhmi.edu

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

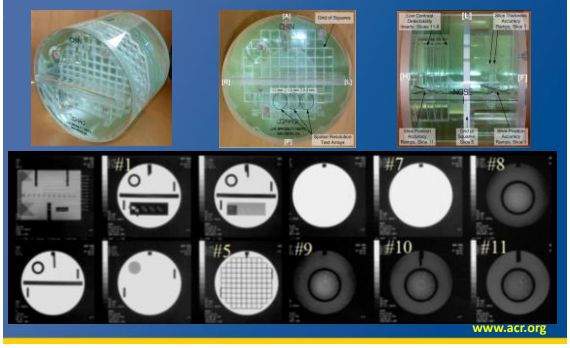
AJR: 188, June 2007

Johns Hopkins mmahesh@jhmi.edu

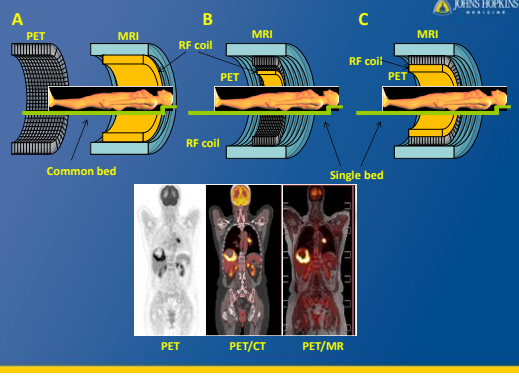
MR Quality Control Tests

- 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



PET-MRI



Johns Hopkins mmahesh@jhmi.edu

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
- http://www.rsna.org/AAPM-RSNA_physics_Tutorials_for_Residents.aspx
- Search for RSNA Online Physics Modules
- https://www.rsna.org/RSNA/AAPM_Online_Physics_Modules_.aspx

Physics articles are among the most-cited articles in RadioGraphics

3. Imaging & Therapeutic Technology
Michael F. McNitt-Gray
AAPM/RSNA Physics Tutorial for Residents: Topics in CT: Radiation Dose in CT
Radiographics November 2002 22:1541-1553; doi:10.1148/rg.226025128
»Abstract »Full Text »Full Text (PDF) »Figures Only

33. Imaging & Therapeutic Technology
Mahadevappa Mahesh
Fluoroscopy: Patient Radiation Exposure Issues
Radiographics July 2001 21:1033-1045
»Abstract »Full Text »Full Text (PDF) »Figures Only

50. IMAGING & THERAPEUTIC TECHNOLOGY - Continuing Medical Education
Robert A. Parry, Sharon A. Glaze, and Benjamin R. Archer
The AAPM/RSNA Physics Tutorial for Residents: Typical Patient Radiation Doses in Diagnostic Radiology
Radiographics September 1999 19:1289-1302
»Abstract »Full Text »Full Text (PDF) »Figures Only

Johns Hopkins mmahesh@jhmi.edu

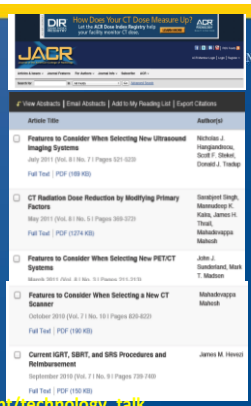
Journal of American College of Radiology

- 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

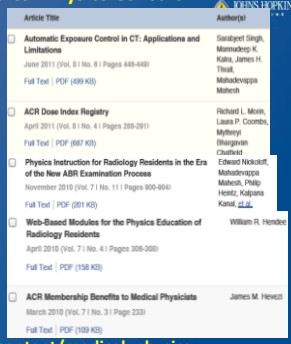
- Feature Editor writes and hosts others' articles about capabilities of new technology and the safe, efficacious practice of radiology



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

Johns Hopkins mmahesh@jhmi.edu

Conclusiongs

- 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