QA FOR IMAGING SYSTEMS USED FOR PLANNING (CT, PET, MR)

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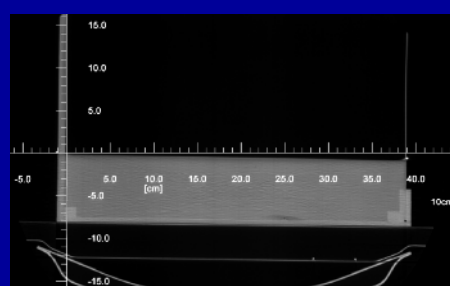
Outline

- Image Quality Concerns for RT
- Acceptance vs Continuing QA
- Selection of QA tasks
- Division of Labor
- Procedure specific processes
  - Fusion
  - CT
  - MRI
  - PET
- Conclusions

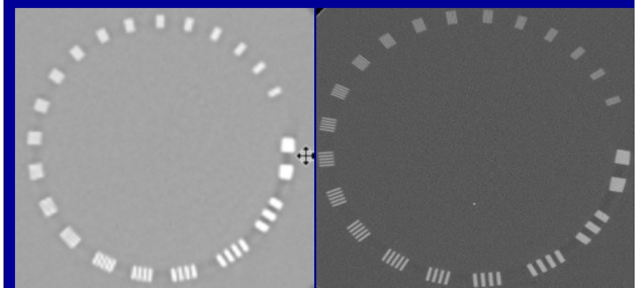
Paradigm Shift

- Imaging equipment in the past was designed for diagnostic radiology and then modified for radiotherapy
- There are new CT scanners that are specifically designed for radiotherapy
- Or they have special features that are designed for radiotherapy
- PET/CT scanners are also designed with RT scanning concerns in mond

Geometric Accuracy

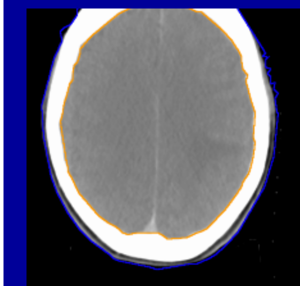


Resolution



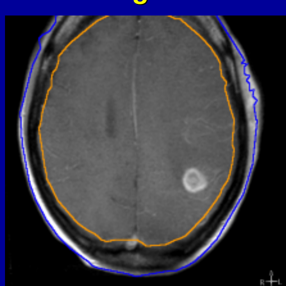
Low resolution High resolution

Computed Tomography



- Primary image set for most treatment planning systems
- Used to define anatomic structures, target volumes, and beam shapes and orientations
- Provides density information for heterogeneity based dose calculations
- DRRs for treatment planning and verification
- The major weakness is the limited soft tissue contrast

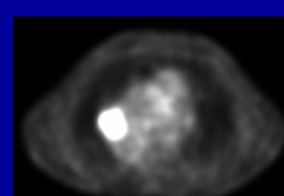
Magnetic Resonance Imaging



- Excellent soft tissue contrast allows better differentiation between normal tissues and many tumors
- It is not limited to imaging in axial planes
- Disadvantages:
  - Susceptible to spatial distortions
  - Image intensity values do not relate to physical or electron density

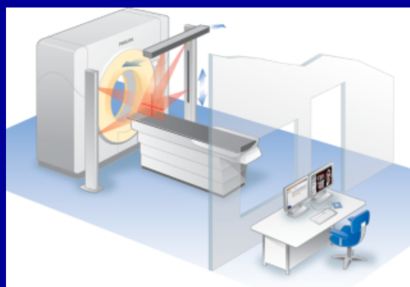
SPECT and PET

- Provide information about physiology rather than anatomy
  - Tumor metabolism
  - Differentiation between tumor recurrence and radiation necrosis
  - Regional lung function
- Poor resolution
  - Difficult to delineate target and organ boundaries
  - Difficult to appreciate external contours

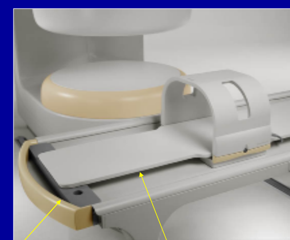


CT simulator

- CT scanner with external lasers
- Flat tabletop
- Virtual simulation software



Panorama 0.23T R/T



Laser bridge

Spacers allow easy Positioning of RF coils

Flat table top insert

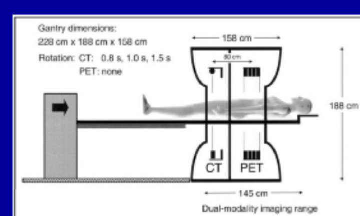
High Field Magnet

- 1.5 T superconducting
- Closed bore
- Flat couch insert added
- Housed in radiology, FCCC

Courtesy Dennis Mah

PET/CT scanner combined unit

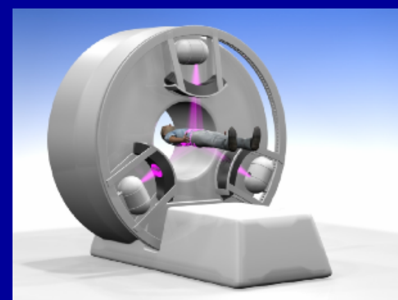
- Multislice CT scanner mated to a PET scanner
- Possibly three scans acquired during procedure
  - Attenuation correction CT
  - PET
  - Treatment planning CT, with contrast if necessary



Adaptive Therapy

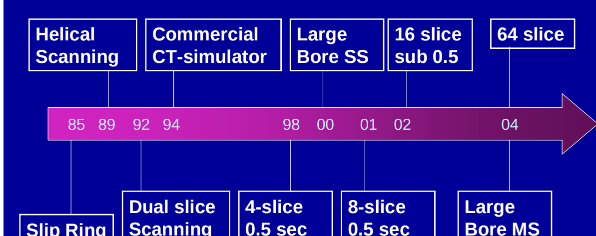
Onboard volumetric imaging

MR-Guided



Viewray Renaissance

CT Time Line



CT Simulator Evaluation

- **Task**
  - Radiation and patient safety
  - CT dosimetry
  - Evaluation of electromechanical components
  - Evaluation of image quality
- **Solution?**
  - AAPM report number 39,
  - AAPM TG53 report
  - AAPM TG66 report

Imaging QA in Radiation Therapy

- Tasks
  - Patient safety
  - Image performance evaluation
  - Evaluation of electromechanical components
  - Process evaluation – data transfer, image registration, image usage, etc.
- Scanner location and primary purpose
  - Diagnostic vs radiation therapy goals
  - Anatomical and biological imaging

Common QA Tasks

- Signal to Noise ratio
- Image Uniformity
- Spatial Linearity
- High-Contrast Spatial Resolution
- Slice Thickness
- Slice Position/Separation
- Image Artifacts
- Laser Alignment
- Couch Alignment
- Quantitative

Image Quality Indicators

- Quantitative
  - Phantom Measurements
    - High Contrast
    - Low Contrast
    - Uniformity
    - Spatial Integrity
    - Artifacts
    - Slice thickness
    - Quantitative accuracy
- Qualitative
  - Physician Preferences
    - Tumor
    - Normal Structures
    - DRR/DCR Objects
    - Workflow
    - Customized protocols

QA in Radiation Therapy

- Commissioning and establishment of baseline performance
- Periodic quality assurance
  - Daily – Perhaps the most important
  - Monthly
  - Annual
- Patient specific QA
- Process QA
- QA Goals

Commissioning and establishment of baseline performance

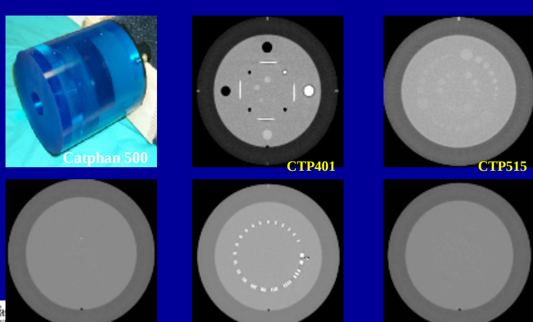
- Verification of scanner performance
- Establishment of baseline data
- Verification of manufacturer phantoms and image analysis tools
- Establishment of imaging protocols – using phantoms to understand differences

Manufacturer phantom

Third-party phantom

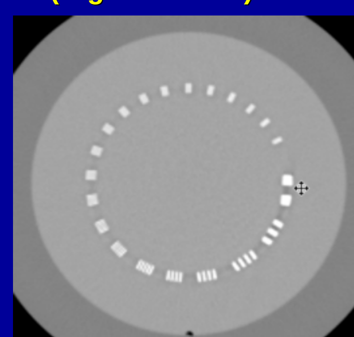
CT QA

Image Performance



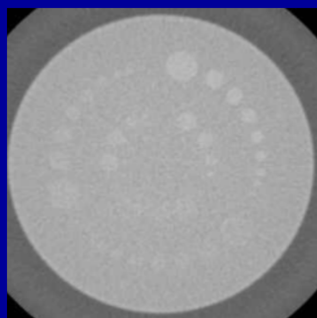
Resolution (High Contrast)

- Ability of the system to record separate images of small objects that are placed very close together

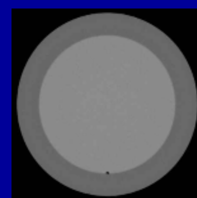


Subject Contrast (Low Contrast)

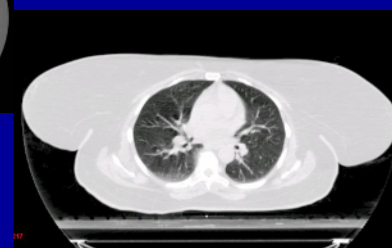
- Ability of a system to resolve adjacent objects with small density differences
- Noise limited



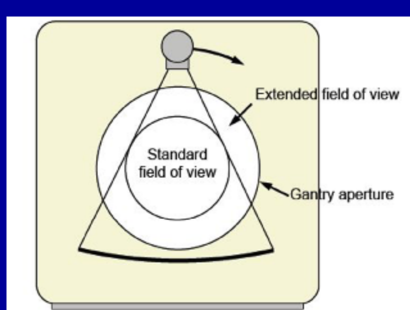
Uniformity and Noise



Measure Daily

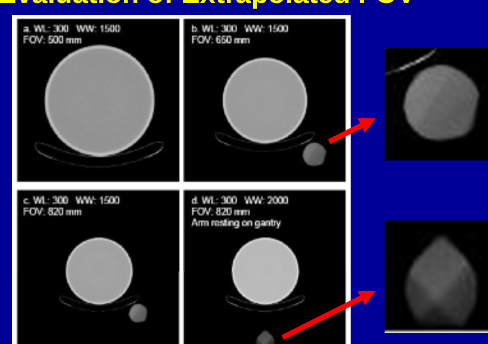


True vs. Extrapolated FOV



From impactscan.org report 05071

Evaluation of Extrapolated FOV



From impactscan.org report 05071

Radiation and Patient safety

- Patient Safety
  - Interlocks
  - Electromechanical
  - Door Interlock
  - CTDI
    - » Definition
    - » Multislice CT
- Radiation Safety
  - Workload – potential pitfall
    - » Significant increase
    - » Shielding design
    - » NCRP 147
    - » Radiation survey

$$X = 60^{-1} \cdot \dot{X} \cdot W \cdot T$$

$$W = N_{CT} \cdot mA_{CT} \cdot t_{CT} + N_{4D} \cdot mA_{4D} \cdot t_{4D}$$

Electromechanical Components

- X-ray Generator
- Gantry Alignment
- Table Alignment/Accuracy
- Laser Alignment/Accuracy

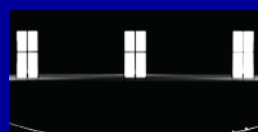
Electromechanical Components x-ray Generator

- Need a non-invasive meter
  - kV accuracy
  - Timer accuracy
  - mA linearity
  - HVL measurements

CT Simulator Mechanical Alignemnt

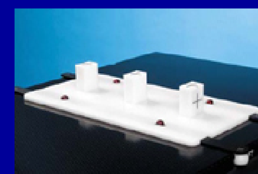
Electromechanical Components
Gantry Alignment/Accuracy

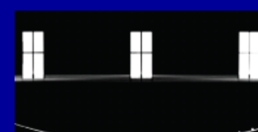
- Gantry tilt accuracy
- Gantry vertical
  - Imaging plane orthogonal to the couch top
- Gantry vertical placement reproducibility
  - Especially important for dual purpose scanners



Electromechanical Components
Table Alignment/Accuracy

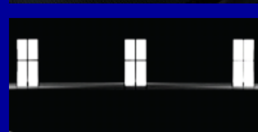
- Tested with weight
  - Settle
  - Sag
- Tabletop motion orthogonal/parallel with the imaging plane
- Table positional accuracy/reproducibility
  - Vertical
  - Longitudinal





Electromechanical Components
Laser Alignment/Accuracy

- Lasers orthogonal/parallel with the imaging plane
- Lasers spacing
- Laser positional accuracy
  - Absolute
  - Linearity
  - Reproducibility
- Coordinate system orientation



MR QA

MR QA Tasks

- Signal to Noise ratio
- Image Uniformity
- Spatial Linearity
- High-Contrast Spatial Resolution
- Slice Thickness
- Slice Position/Separation
- Image Artifacts

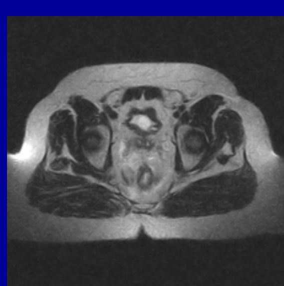
AAPM Report #28, Med Phys 17, 1990

MR Spatial Distortions

- Inhomogeneity of main magnetic field
- Nonlinearities of the spatially encoding gradient magnetic fields
- Alteration of magnetic fields by imaged objects

Disadvantage of MRI Sim: Distortion

- Bigger patients can produce significant distortions
- Patient was >300 lbs



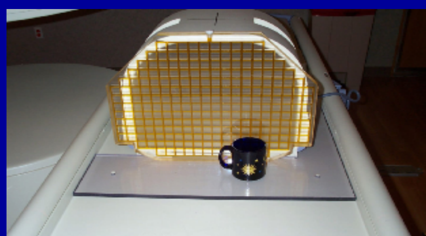
Courtesy Dennis Mah

Gradient Distortion Correction

- Design trade-offs limit linearity of gradients
  - Can improve linearity, but at loss of performance
- System is optimized based upon design trade-offs
- Compute gradient magnetic field from engineering diagrams
- Derive correction terms for theoretically predicted magnetic field
- Mathematically correct the MR images using correction factors

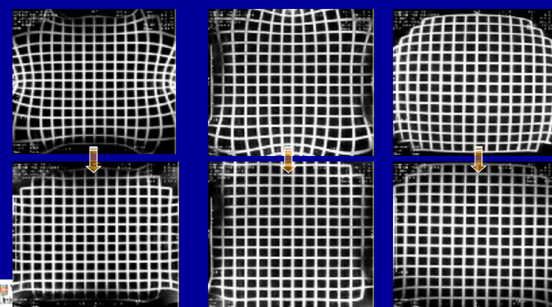
Courtesy Dennis Mah

Phantom



Courtesy Dennis Mah

GDC – Gradient Distortion Correction

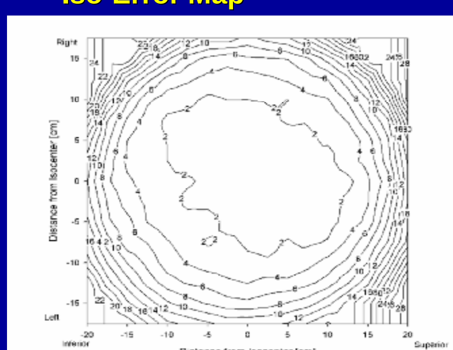


Axial Sagittal Coronal

Courtesy Philips Medical Systems, Inc.

Iso-Error Map

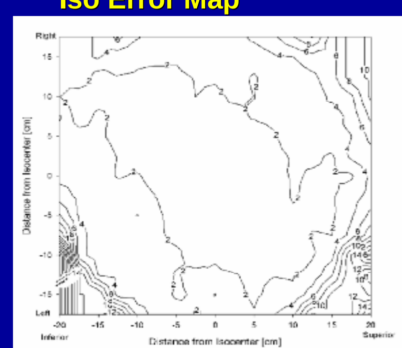
Before GDC



Courtesy Dennis Mah

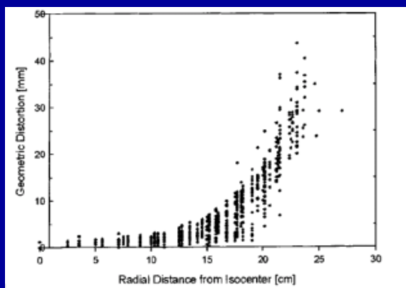
Iso Error Map

With GDC



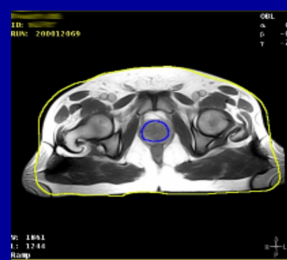
Courtesy Dennis Mah

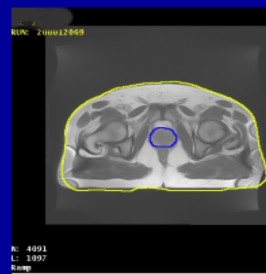
Image Distortion Away from Isocenter



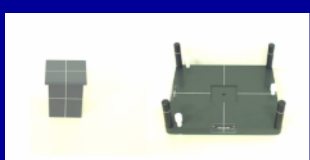
Courtesy Dennis Mah

Distortion Corrections



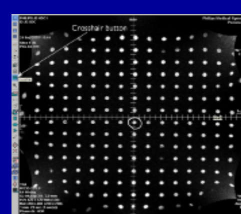


Courtesy Dennis Mah



– QA Phantom
– For evaluating lasers with MR Sim

- Image distortion evaluation phantom
  - **The phantom and SW is intended for evaluation of residual geometrical distortions in images.**



Courtesy Dennis Mah

PET QA

Quality Assurance in PET

- Whether the camera is a dedicated PET camera or a combined PET/CT camera, the first step for image quality is the detector setup.
- Most PET detectors are composed of detector modules made of scintillator block and an array of 4 PMTs.
- The setup of those block for proper operations includes the adjustments of:
  - Constant Fraction Discriminator (CFD)
  - Timing alignments
  - XY profiles
  - Energy Calibration
  - Look up table for crystal boundary identification.

This step is called the block setup procedure

Courtesy Richard Laforest

Detector Module

- Small crystals for high resolution
- Small Gaps for high sensitivity
- Large tubes for fast, stable timing
- Light sharing scheme for position encoding
- Lower cost, better reliability than individual crystals, small tubes.

Courtesy Richard Laforest

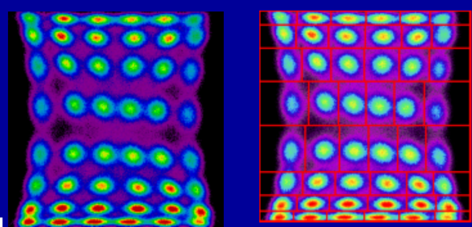
Normalization

- Every pair of detector does not have exactly the same detection efficiency.
- The fluctuations in detection efficiency from the different lines of response is compensated by the normalization procedure in which a uniform source of activity is used to measure the intrinsic detection efficiency for each line of response and the resulting normalization file is kept on the computer memory.

Courtesy Richard Laforest

Position Encoding

- Flood histogram slightly distorted.
- Use look-up table (LUT) to identify the crystal number struck.



SUV Calibration

- Absolute Quantitation is important in PET as it allows to extract the activity concentration in each voxel.
- Performed using a cross-calibration uniform cylinder containing a know amount of radio-activity, most likely a uniform Ge-68 cylinder or a fillable F-18 cylinder.

PET Quality Control

- Quality control in ensure on a daily basis by performing a blank transmission scan (on a dedicated PET scanner equipped with Transmission rods) and compared with a standard blank (one acquired immediately after detector setup).
- Inspection of sinograms to identify missing blocks or suspicious artifacts.

Schedule for Quality Assurance

- Detector Setup (every 3 to 6 months) or anytime a maintenance is performed on the scanner.
- Normalization and calibration following every detector setup.
- Daily inspection of sinograms and daily blank transmission scan.

IMAGE REGISTRATION QA

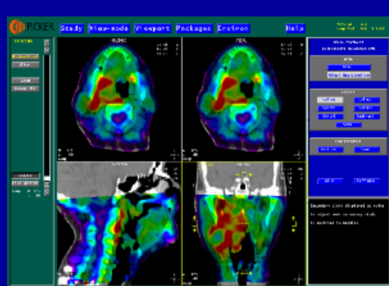
AAPM TG# 132

Multimodality Image Fusion

- Quality Assurance Issues:
  - Image data integrity after transfer
  - Image spatial integrity
  - Image fusion accuracy
  - Overall software functionality

Multimodality Image Fusion

- Fusion Techniques:
  - Surface-based Registration
    - » Internal
    - » External
  - Image-based Registration
  - Point-based Registration
  - Automatic and semiautomatic computer assisted methods



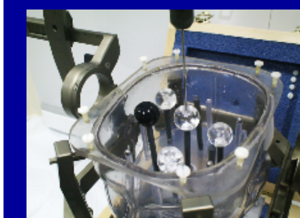
Sterotactic Localization Phantom

- Anthropomorphic head phantom
- Developed for assessment of stereotactic localization accuracy
- Plastic spheres and rods located throughout the phantom
- Coordinates of points within spheres and rods from CT and MR images compared with physical measurements

Mutic *et al* - Int. J. Radiat. Oncol. Biol. Phys., 51, 255-260, (2001).

Sterotactic Localization Phantom

Sterotactic Localization Phantom



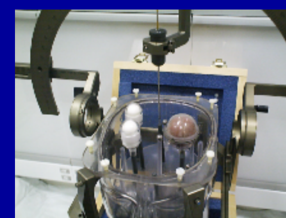
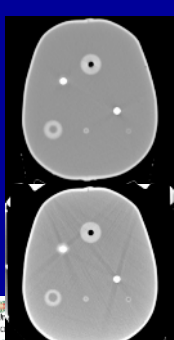
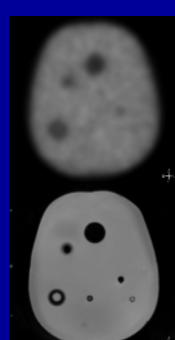


Image Correlation



- CT (mask)
- CT (ring)



- PET (mask)
- MR

Image Correlation

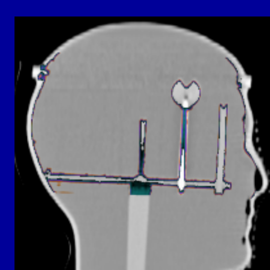


Image Correlation

CT with CT | CT with MR | CT with PET

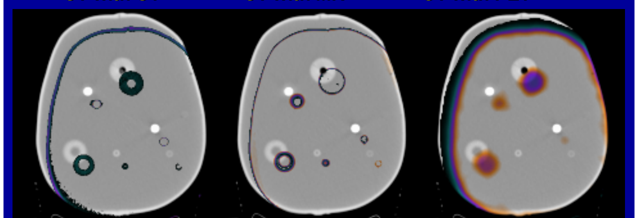
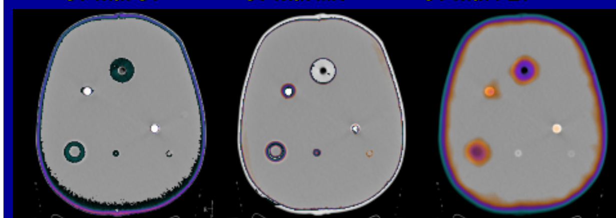


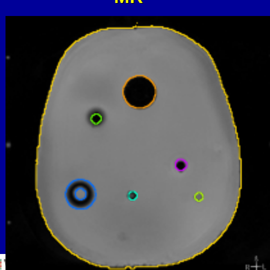
Image Correlation

CT with CT | CT with MR | CT with PET

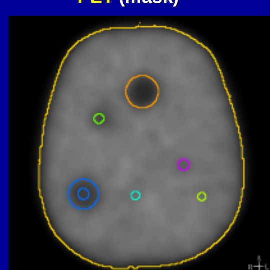


Contour Correlation

MR



PET (mask)



Conclusion

- Accurate target identification remains one of the greatest avenues for improvement in the radiation therapy treatment planning
- Multimodality imaging is a valuable tool in this process and its use in radiation oncology is constantly increasing
- CT will remain the primary imaging modality in RT
- Implementation of multimodality scanner in radiation therapy setting increases demands on therapy physicist's expertise in imaging QA
- Help from diagnostic physicists is very important in this process