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 mind

Geometric Accuracy
Resolution

- 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

Computed Tomography

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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 tabletop insert

High Field Magnet

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

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

- Helical Scanning
- Commercial CT-simulator
- Large Bore SS
- 16 slice sub 0.5
- 64 slice
- Slip Ring
- Dual slice Scanning
- 4-slice 0.5 sec
- 8-slice 0.5 sec
- Large Bore MS

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

Image Performance

CT QA

Resolution (High Contrast)

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

Manufacturer phantom

Third-party phantom

CT QA

Image Performance
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

**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 Alignment**
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

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

**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

GDC – Gradient Distortion Correction

Axial  Sagittal  Coronal

Iso-Error Map

Before GDC

With GDC

Iso Error Map

Before GDC

With GDC
Image Distortion Away from Isocenter

Distortion Corrections

- 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.
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.

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.

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.
**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 known amount of radio-activity, most likely a uniform Ge-68 cylinder or a fillable F-18 cylinder.

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**PET Quality Control**

- Quality control is ensured 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.
Multimodality Image Fusion

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

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

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 physicists’ expertise in imaging QA.
- Help from diagnostic physicists is very important in this process.