Imaging Equipment Specification and Selection in Radiation Oncology Department

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Presentations

4:30PM	What Therapy Physicists Need to Know About **CT and PET/CT**: Terminology and Latest Developments
5:00PM	An **MRI** Simulator from Proposal to Operation
5:30PM	PET/CT and MRI in Radiation Oncology: **Program Considerations**

What Therapy Physicists Need to Know About CT and PET/CT: Terminology and Latest Developments

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Disclosure

No conflict of interest.

No vendor support or financial interests in any of the commercial products discussed as part of this presentation.

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Outline

1. Latest developments of CT and CT simulator
2. Important CT terminology
3. Technical specification and quote of CT simulator
4. Latest developments of PET-CT
5. Important PET-CT terminology
6. Technical specification and quote of PET-CT
7. Summary

CT

CT and CT Simulators Are Not Built Equal

- CT simulators have larger bore, true FOV, extended FOV, and high accuracy couch

True scan FOV (cm)	Extended FOV (cm)	Bore size (cm)	Model
50	65	80	GE Discovery 590 RT
50	80	80	Siemens Definition AS Open
60	70	85	Philips Brilliance Big Bore
70	85	90	TOSHIBA Aquilion LB


GE Discovery CT590 RT


Siemens Definition AS Open

- Flagship models of diagnostic CT –
  - high power X-ray generators
  - high tube current capability
  - high heat capacity
  - fast rotation
  - higher spatial resolution
  - high volume coverage in a single rotation.


Philips Brilliance Big Bore


TOSHIBA Aquilion LB

Courtesy of GE Healthcare, Siemens Medical Solutions, Philips Health Systems, and TOSHIBA Medical Systems

CT Developments: Metal Artifact Reduction

- Estimating and subtracting the metal-only sinogram
- Improve anatomical visibility
  - avoid subjective density overrides
  - improve dose calculation accuracy
  - improve proton range accuracy
- Use with caution – residual artifacts and secondary artifacts
- Dual energy CT is another approach for reducing metal artifacts
- Siemens iMAR (Iterative Metal Artifact Reduction)
  Siemens MARIS (Metal Artifact reduction in Image Space)
  Philips O-MAR (Metal Artifact Reduction for Orthopedic Implants)
  GE MAR (Smart Metal Artifact Reduction)
  TOSHIBA SEMAR (Single Energy Metal Artifact Reduction)

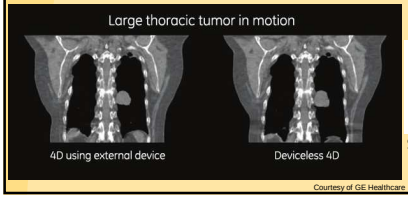
Courtesy of Siemens Medical Solutions

Courtesy of Philips Health System

Courtesy of GE Healthcare

CT Developments: 4D CT Improvement

- Improvements in viewing and 4D workflow
- Acquisition modes – retrospective low-pitch spiral and prospective cine
- Phase-, amplitude-, and time-based binning
- Use external devices (belt, block, marker) or **internal anatomical metrics** (deviceless) to determine the breathing signal. (Deviceless respiratory motion corrected PET is being studied.)



Courtesy of GE Healthcare

Courtesy of Tinsu Pan (AAPM 2015 meeting, Martin et al TU-G-CAMPUS-J-13)

CT Developments: Statistical Iterative Reconstruction

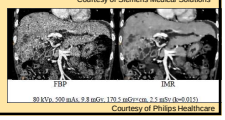
- New algorithms to reduce noises while preserving high contrast edges
- Improve 4DCT quality, GTV and OAR delineation, or reduce CT scan dose
- Previous non-model based

Siemens SAFIRE (Sinogram Affirmed Iterative Reconstruction)
Philips iDose4
GE ASiR (Adaptive Statistical Iterative Reconstruction)
TOSHIBA AIDR (Adaptive Iterative Dose Reduction)

New model-based

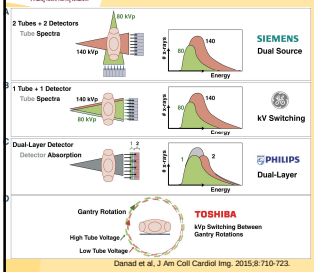
Siemens ADMIRE (Advanced Modeled Iterative Reconstruction)
Philips IMR (Iterative Model Reconstruction)
GE MBIR (Model-based Iterative Reconstruction)
TOSHIBA AIDR-3D (Adaptive Iterative Dose Reduction 3D)

Courtesy of Siemens Medical Solutions



Courtesy of Philips Healthcare

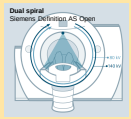
CT Developments: Dual Energy/Spectral CT



Danad et al, J Am Coll Cardiol Img. 2015;8:710-723.

- Old concept but new technology. Very few installations in radiation oncology.
- Single source (single vs dual layer detector) vs. dual X-ray sources

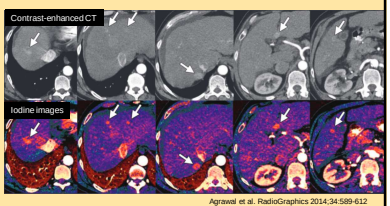
Siemens Definition AS Open (Single source, dual rotations)
Siemens TwinBeam (Single source, split filters Au/Sn, single rotation)
Siemens Definition Flash and Force (Dual sources, single rotation)
Philips IQon (Single source, spectral detector, simultaneous acquisition)
GE (Single source, fast kVp switching)
TOSHIBA Aquilion (Single source, kVp switching with each rotation)



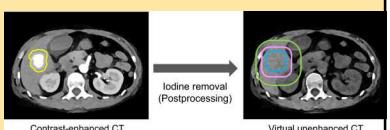
Courtesy of Siemens Medical Solutions

CT Developments: Dual Energy/Spectral CT

- Synthesize monochromatic images (single keV), iodine and iodine-subtracted virtual unenhanced images.
- Produce effective Z map of tissues. Work in progress on ρ map.
- Potential impact in brachytherapy and Monte Carlo dose calculation, and proton stopping power estimation.



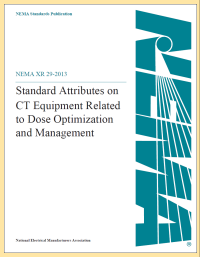
Agrawal et al. RadioGraphics 2014;34:589-612



Yamada et al. Radiat Oncol 2014;9:168

CT Developments: Compliance With Dose Reporting

- Compliance with **NEMA standard XR-29-2013** for improved CT radiation safety and avoid reduction in Medicare reimbursement
- NEMA XR-29 (MITA SmartDose Standard) includes
  - **DICOM-compliant radiation dose structured reporting**
  - **Dose check features**
  - **Automatic exposure control**
  - **Reference adult and pediatric protocols**
- Some existing CT scanners can meet requirements with software upgrade. New scanners should be compliant with XR-29.
- Currently only applicable to diagnostic CTs. But for CTs that do both diagnostic and RT sim, they have to comply.



CT Developments: Dose Management Tools

	Siemens	Philips	GE	Toshiba
Automatic Exposure Control Trade Name	CARE Dose 4D	DoseRight 3D-DOM	Smart mA	SURE Exposure 3D
Image Quality Reference Indicator	Quality reference mAs	Reference image	Noise index	Target image quality level
Available Features	Dose notification Dose alert DICOM dose report DoseLogs DoseMAP	Dose notification Dose alert DICOM dose report Locking protocols	Pre-scan dose estimates Dose check DICOM dose report	Dose notification Dose alert DICOM dose report

Dose notification: a message is triggered when a **single planned scan** is likely to exceed the pre-programmed $CTDI_{vol}$ or DLP value

Dose alert: a message is triggered when the **cumulative dose** at a location plus the dose for the next planned scan, is likely to exceed a pre-programmed value

The purpose is to present a **time-out opportunity** for operators to check scan setting that leads to a higher than usual dose index.

Important CT Terminology (A Partial List)

kV or kVp (tube potential, 120 KV typically the only one used for CT sim)

mA (tube current, modulation techniques to reduce patient scan dose)

mAs = mA × exposure rotation time per rotation

effective mAs or mAs per slice = mAs/pitch (reflect the effect on absorbed dose when pitch is changed)

pitch = table travel per gantry rotation/total nominal beam width

collimation (affect thinnest available reconstructed slice, determined together with desired slice width, impact scan time and dose efficiency)

scout/topogram/surview/scanogram (projection radiograph for users to prescribe CT scan range)

spatial resolution (typically specified as line pair/mm visible for high-contrast bar pattern)

low-contrast resolution (ability to discriminate between tissues with slightly different attenuation)

AEC (automatic exposure control, scanner feature to adapt tube current to patient size to reduce dose)

$CTDI_{vol}$ (CT dose index calculated by scanner, dose to 16 or 32 diameter PMMA phantom, independent of what patient is actually scanned)

DLP (dose length product, mGy·cm)= $CTDI_{vol}$ (mGy) x scan length (cm) (another dose metric, more direct bearing than CTDI on the overall radiation risk of CT scan)

beam hardening artifact (dark streaks near high attenuating objects or cupped appearance)

Good resources: AAPM website CT Lexicon
McNitt-Gray presentation of key CT parameters at 3rd CT dose summit

CT Simulator: Technical Specification and Quotation

- Technical specification and quotation are separate documents.
- **Key specifications of CT simulator** include

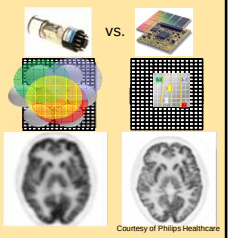
  gantry opening, rotation time, generator (power rating, kVp setting, mA range), X-ray tube (focal spot sizes, heat capacity, cooling rate), CT detector (material, slices, z-axis coverage, material, slice thickness, scan FOV), image quality (spatial resolution, low contrast resolution, noise), reconstruction and display, table, and external localization laser
- Quotation lists items to purchase, part numbers, quantity, brief description for each item, rigging and installation, total price. Several revisions.
- **Key quotation items of CT simulator** include

  CT scanner, selected slice configuration, power generator, image acquisition, 4D CT package, dose management tools, RTP table and tabletop, external lasers, cooling system, chiller, server, CT simulation and advanced applications (metal artifact reduction), iterative reconstruction package, old simulator trade-in, on-site and off-site training

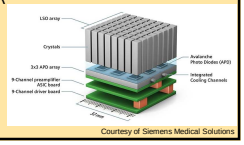
PET-CT

PET-CT Developments: Digital Detectors

- Directly coupled to scintillator crystals and convert scintillation light to a digital signal.
- Replace conventional analog photomultiplier tubes and analog-to-digital converter.
- Improvements in resolution, sensitivity, and potentially quantitative accuracy
- Example: Digital silicon photomultiplier (SiPM) in Philips Vereos PET-CT (325 ps resolution)
- Avalanche photo diode (APD) in Siemens mMR PET-MR and SiPM in GE SIGNA PET-MR — photomultiplier tubes are sensitive to magnetic fields



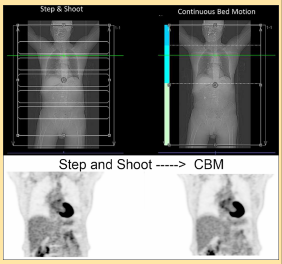
Courtesy of Philips Healthcare



Courtesy of Siemens Medical Solutions

PET-CT Developments: Acquisition with Continuous Bed Motion

- Conventional PET acquisition is **bed-based** (stop and go, 1.5-3 min/bed position). Brain-only imaging acquired with a single bed position (5-10 mins).
- **25-50% overlap** between adjacent bed positions (scanner dependent) is needed to minimize the axial non-uniformity of the noise. This increases total acquisition time.
- Typical continuous acquisition 1-2 mm/sec (0.1-10 mm/sec)



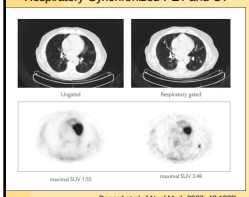
Osborne et al. Am J Nucl Med Mol Imaging 2015; 5(1): 56-64

- Allow physicians to scan the desired area without CT over-scanning in axial axis in step-and-go acquisition. Bed moving may give patients a sense of progress.

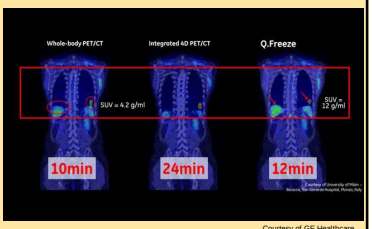
PET-CT Developments: Respiratory Management

- 4D time-of-flight respiratory correlated imaging
- Use the entire acquired data to generate a 3D motion-corrected image. Higher SNR for better lesion detection and SUV quantification.

Respiratory Synchronized PET and CT



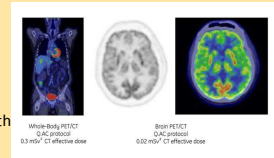
Benard et al, J Nucl Med. 2007; 48:123P



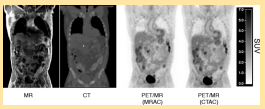
Courtesy of GE Healthcare

PET-CT Developments: Ultra Low Dose CT for Attenuation Correction

- When CT is not used for diagnosis, anatomical localization, or treatment planning, CT tube current may be reduced but still sufficient for attenuation correction.
- 5-10 mAs and < 1mSV effective dose with current scanners has been reported for children and selected adults
- Estimate attenuation maps of head based on PET data alone (Siemens Smart Neuro AC)
- MR-based PET attenuation correction (MRAC and UTE methods) in PET-MR



Courtesy of GE Healthcare

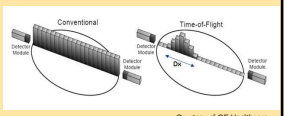


Izquierdo-Garcia et al. Eur J Nucl Med Mol Imaging 2014;41: 1574-1584

PET-CT Developments: Time of Flight and Point Spread Function

Time of Flight Imaging

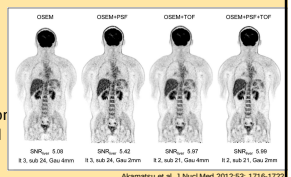
- Measure arrival time difference between two photons to determine the annihilation origin along the line of response with a smaller uncertainty.
- Improve structural detail (SNR) particularly in large patients



Courtesy of GE Healthcare

Point Spread Function Modeling

- PSF is the response of an imaging system to a point source.
- Modeling PSF in image reconstruction helps improve spatial resolution and correct partial volume effect.



Akamatsu et al. J Nucl Med 2012;53: 1716-1722

Important PET Terminology (A Partial List)

transverse spatial resolution (FWHM of point spread function of a point source, typically specified at 1cm and 10cm from FOV center on the transverse plane)

axial spatial resolution (same as above, resolution in the scanner axis direction)

sensitivity (in cps/kBq/cc, measure of counting efficiency of a PET scanner, the number of coincidence events per unit time detected by the scanner for each unit of source activity)

peak true count rate (in kcps, the maximum count rate, which occurs at a certain level of activity, beyond which the system is paralyzed)

noise equivalent count rate (NECR in kcps, estimate of the number of true coincidences necessary in an ideal system to reach the SNR obtained in a real system with scatter and random coincidences, proportional to SNR^2 so good for scanner performance comparison)

timing resolution (in picosecond, minimum time interval between two subsequent photon events in order for these to be detected as separate events)

energy resolution (the precision with which the PET system can measure the energy of incident photons)

scatter fraction (ratio of scatter counts to total counts)

OSEM (ordered subset expectation maximization, iterative algorithm for image reconstruction)

time of flight (TOF, a technique to detect the difference in time between the detection of the two photons for better localizing the point of origin of the annihilation event)

PET-CT: Technical Specification and Quotation

- **Key specifications of PET** include

  gantry opening, PET detector (crystal material and size, number of crystal, axial and transaxial FOV), Pet performance (transverse spatial resolution at 1 and 10 cm, axial low resolution at 1 and 10 cm, timing resolution, time-of-flight localization accuracy, system sensitivity, peak and clinical NECR, peak trues, scatter fraction, energy resolution)

- **Key quotation items of PET-CT** include

  PET-CT scanner, computer systems, RTP package for PET-CT simulator including flat table top and CT sim software, external lasers, cooling system, chiller, calibration sources and phantom, CT and PET respiratory gating package, respiratory trigger system, time-of-flight toolkit, CT dose management tools, CT iterative reconstruction, image fusion package, image transfer and storage, server, UPS, contrast injector, on-site and off-site training

Summary

- Metal artifact reduction, modeled-based statistical iterative reconstruction, spectral CT, and radiation dose management are latest innovations of CT scanners.
- Digital PET detectors, continuous bed motion, ultra low dose CT for attenuation correction, time of flight and point spread function modeling are new PET-CT technologies.
- Important terminology, technical specification, and quotation of CT and PET-CT are reviewed.
- Understanding and better utilizing new imaging technologies will advance radiation therapy and improve patient care.

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