CT in Radiation Therapy

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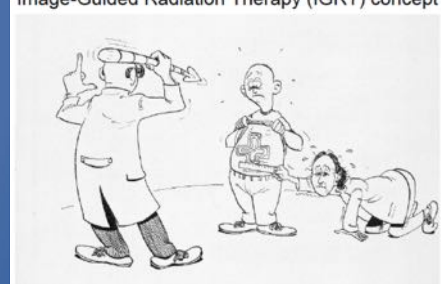
Introduction

- Computed Tomography (CT) is most widely used imaging modality in radiation therapy and is basis for treatment plans
- CT-based image-guided radiotherapy (IGRT) systems allow management of geometric variations in patient setup and organ motion

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)

IGRT Systems

- Medical linear accelerator (LINAC) manufacturers and third party vendors have developed integrated imaging systems to
  - Improve and facilitate patient anatomy visualization
  - Enable efficient positioning of anatomical structures relative to treatment room
- Systems often use accelerator iso-center as reference point

IGRT Systems

- Clinical implementation of both kV-CBCT and MV-CBCT systems requires calibration procedures that correct for accelerator and imaging component sags and flexes and to properly register to treatment beam iso-center

CT Technologies in Image Guided Radiation Therapy

- CT-on-rails
- Kilo-voltage Cone-beam CT (kV-CBCT)
- Fan-beam Megavoltage CT (MVCT)
- Megavoltage Cone-beam CT (MV-CBCT)

CT-on-Rails

- Earliest implementation of volumetric IGRT system
- Diagnostic CT scanner integrated into RT system
- Integrated CT-LINAC system has CT scanner mounted on rails in same room

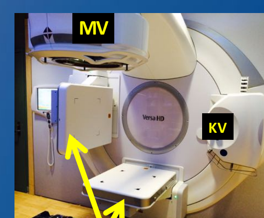
Dong L, MD Anderson Cancer Center

CT-on-Rails

- Treatment couch rotates between CT and LINAC while patient remains immobilized between imaging and treatment
- Image quality from low-dose CT imaging is sufficient for image alignment
- Diagnostic CT effective doses - 0.1 – 20 mSv, Imaging doses in therapy can be 2-4 lower when used for daily targeting

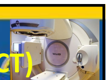
kV-CBCT integrated with LINAC

- 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

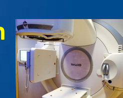
kilo-Voltage Cone-beam CT (kV-CBCT)



- kV-CBCT produces CT data set (not of diagnostic image quality but with sub-millimeter spatial resolution) generally adequate for imaging bone and even soft tissues
- CT – fan beam (0.6 – 10 mm beam width)
- kV-CBCT
  - Cone beam (14-26 cm) with slow gantry rotation
  - Fluoroscopy mode (2 projections per degree with 195-360° arcs)

kilo-Voltage Cone-beam CT (kV-CBCT)

- kV-CBCT image quality is limited compared to traditional CT due to
  - Motion blur due to long acquisition time
  - Scatter radiation due to volumetric image acquisition
  - Image artifacts
- Doses - 0.2 to 2 cGy per acquisition



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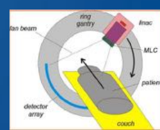
Fan-beam Mega Voltage CT (MVCT)

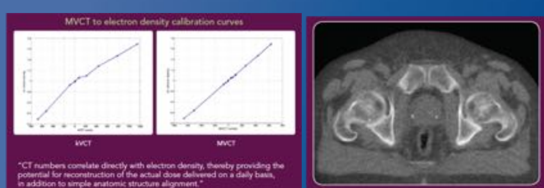
- Helical Tomotherapy®
- Images patient in treatment position
- Imaging beam produced by same accelerator that generates treatment beam, both with nominal electron beam energy reduced to 3.5 MeV for fan-beam MVCT



Fan-beam MVCT

- Compared to kV-CBCT, fan-beam MVCT have fewer scatter and beam-hardening artifacts
- Using Megavoltage x-rays for imaging eliminates artifacts due to high-Z materials than kV-CBCT, however, MCVT images are inherently poor subject contrast
- Doses range from 1 to 3 cGy per scan

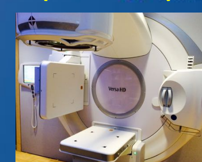
Fan beam MVCT Accuracy and Image Quality



TomoTherapy - Accuray

Megavoltage cone-beam CT (MV-CBCT)

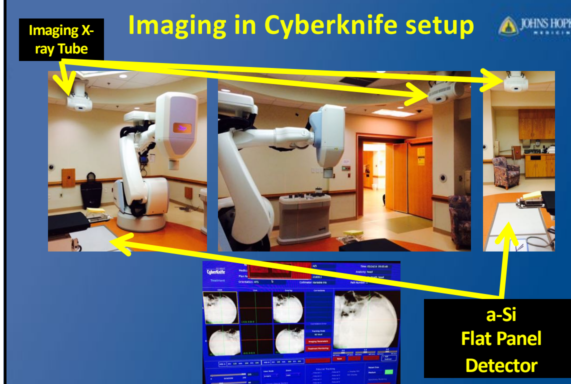
- Flat panel (amorphous-Silicon (a-Si) adapted for MV imaging attached to LINAC and integrated to generate 3D representation of patient in treatment position
- Similar to fan-beam MVCT, MV-CBCT images have poor subject contrast but immune to typical high-Z artifacts



Megavoltage cone-beam CT (MV-CBCT)

- Known for simplicity
- Geometry provides easier access to patient
- Image directly referenced to beam - simplify QA
- Imaging dose can be straight forwardly accounted for in treatment planning
- Doses range
  - 3 to 10 cGy per scan (daily lower end)
  - 6 to 10 cGy per scan (tumor monitoring studies)

Imaging in Cyberknife setup



Commercially available CT-based IGRT systems

Make and model		Elekta XVI	Varian On-Board Imager	Siemens Artiste	TomoTherapy	Siemens Primatom
Imaging configuration		kV-CBCT	kV-CBCT	MV-CBCT	MVCT	kVCT-on rails
Field of view		50 × 50 × 25.6	45 × 45 × 17	40 × 40 × 27.4	40 cm	50 cm
Correction method	Translation	Automatic couch motion	Automatic couch motion	Automatic couch motion	Automatic in 2 directions	Manual couch motion
	Rotation	Optional	None	None	Optional	Optional
Geometric accuracy		Submillimeter	Submillimeter	Submillimeter	Submillimeter	Submillimeter
Dose (cGy)		0.1–3.5	0.2–2.0	3–10	0.7–3.0	0.05–1
Image acquisition and reconstruction time		2 min	1.5 min	1.5 min	5 s per slice	3 s per sec

AAPM TG 179

Target Localization Technologies

Image Dose

- CT-based imaging studies report dose ranges
  - 0.1 to 2 cGy/scan for kV-CBCT
  - 0.7 to 10.8 cGy/scan for mV-CBCT
  - 0.7 to 4 cGy for fan-beam MVCT
- Dose can cumulate from 3 to 370 cGy over course of treatment
- Adapting dose reduction strategies is key (AAPM Task Group 75)

Conclusions

- CT-based image-guidance systems have potential to change how RT is delivered
- Image quality requirements for QA differ
- Primary aim of image guidance is to detect and correct positional uncertainties, hence geometric accuracy assessment is key

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