1

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Learning objective

The objective of this educational session is

to review KV-CBCT and MV-CBCT

imaging systems for daily localization

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Outline

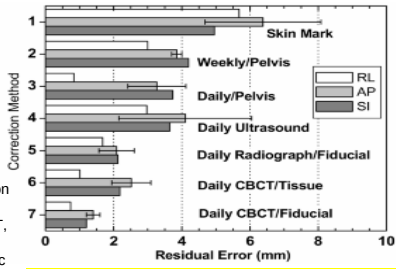
1. Commissioning, image quality, dose, registration process, and acquisition modes
2. Clinical integration
3. QA, stability over time, and downtime
4. Standard clinical applications
5. Novel clinical applications
6. Technology evolution and future directions

Why CBCT?

- Advances in treatment planning and delivery systems allow for higher doses to target and lower dose to normal tissue
- With the resulting steep dose gradients, motion management (inter and intra- fraction) becomes more critical
- Tumors often not visible in 2D images
- Role of CBCT is to help reduce interfractional motion and try to assess patient status (tumor evaluation, adaptive planning, ..)

Analysis of IGRT Studies

- Performance of various IGRT correction methods in the prostate
- Residual error indicates the remaining deviation after correction of the prostate centroid from its planned position
- Not all prostate localization methods are considered here (in-room CT, MV CT, optical guidance, implanted electromagnetic fiducials)



Mageras et. al. Planning in the IGRT context-closing the loop, Semin Radiat Oncol. 2007 17(4): 268-77

KV CBCT

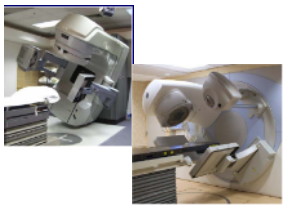
Retractable X-ray tubes and amorphous silicon detectors

Mounted at 90 degree from the treatment room beam CAX

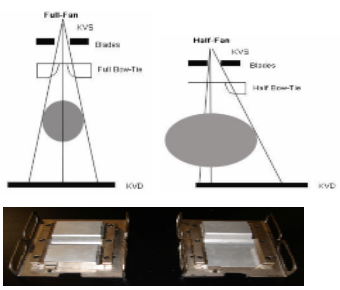
Acquiring projections (full, half, partial-rotation) around the patient to construct 3D or 4D information

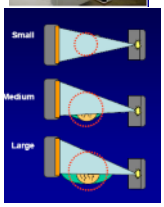
Acquisition time ~ 1min

Reconstruction time



Modes of Acquisition





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Problem with CBCT???

- Large quantity of scattered radiation in the patient reaching the detector
- Scatter reduces contrast and contributes additional noise and induces localized artifacts
- Scattering within the patient can contribute additional dose to the patient

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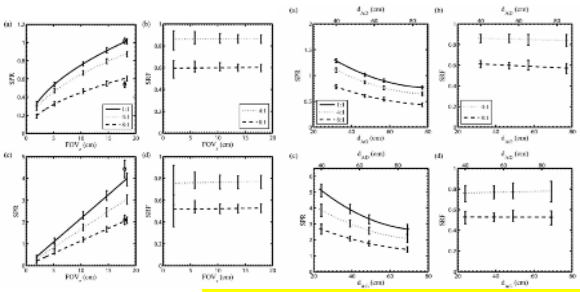
CBCT Image Quality-Scatter Reduction



Graham S, Moseley D et. al. Compensators for dose and scatter management in cone-beam computed tomography 2007 Med. Phys. 34(7): 2691-2703

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To improve the image quality of kV CBCT the following modifications could be made except:

20%	1. utilizing compensating filters with large modulation factors
20%	2. scatter correction algorithms
20%	3. adjusting the air gap between the patient and the detector
20%	4. reducing the longitudinal FOV
20%	5. utilizing grids

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To improve the image quality of kV CBCT the following modifications could be made except:

1. utilizing compensating filters with large modulation factors
2. scatter correction algorithms
3. adjusting the air gap between the patient and the detector
4. reducing the longitudinal FOV
5. utilizing grids

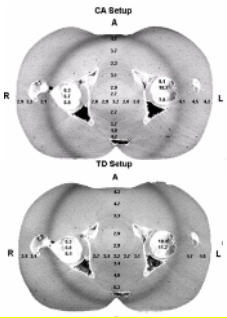
answer is (1)
Ref:
Graham MA, Moseley DJ, et al. 2007 Compensators for dose and scatter management in cone-beam computed tomography *Med Phys.* 34(7):2691-703

Patient Dose from CBCT

- System Dependent
  - kV/ mA
  - Number of projections
  - kV system properties (bow-tie)
  - kV system field size
- Patient Dependent
  - Size/shape of patient
  - Body part
- What is our interest?
  - risk/ benefit ratio needs to be considered

CBCT Dose

- Dose were measured using phantom and in-vivo TLDs for prostate patients
- AP skin doses ranged from 3-6 cGy for 20-23 separation
- The Lt skin dose was ~4.0 cGy while Rt lat skin was ~2.6 cGy (due to gantry rotation)
- Central dose was ~3.0 cGy
- The left hip received 10-11 cGy while the right received 6-7 cGy



Wen N, Guan H, Hammoud R et. al. Dose delivered from Varian's CBCT to patients receiving IMRT for prostate 2007 Phys. Med. Biol. 53(11): 2897-909

CBCT Dose Reduction

Dose reduction can be accomplished by the reducing the exposure (mA, mS)→ image quality

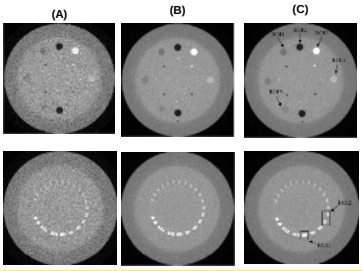
The aim is to improve the low dose image quality by reducing noise in the sinogram before image reconstruction

(A) 10 mAs

(B) 10 mAs with noise reduction algorithm

(C) 80 mAs

Experimental results indicate the possibility to reduce the CBCT dose by a factor of 1/8 without loss of useful information



Wang J. et. al. Dose reduction for Kilovoltage Cone Beam CT in radiation therapy 2008 Phys. Med. Biol. 53(11): 2897-909

The management of imaging dose during image-guided radiotherapy:
Report of the AAPM task group 75 (Murphy et. al.)

- Local dose vs integral dose:
  - local can be reduced only by the fuence
  - Integral dose by decreasing either fluence or area/volume irradiated
  - ALARA to keep both as low as possible
- Planar vs axial imaging
  - Planar imaging the dose to the patient is the greatest at the skin surface nearest to the source and falls off progressively as the radiation transmits through the body
  - Axial imaging dose by design is distributed uniformly

120 kVp, 660 mAs, SDD=155 cm , 41x41 cm

Parameter	Head	Chest
Mean dose at center (mGy)	29	16
Mean skin dose (mGy)	30	23
Effective dose (mSv)	3.0	8.1
Conversion factor (mSv/mGy cm^2)	6.0×10^{-5}	16.0×10^{-5}

Islam MK et. al. Patient dose from kilovoltage cone beam computed tomography imaging in radiation therapy 2006 Med. Phys. 33: 1573-82

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Keeping the other factors the same, patient dose (central mean dose) from KV CBCT will be increased with:

20%	1. decreasing the kV/mAs settings
20%	2. scanning thinner patients
20%	3. decreasing the number of projections
20%	4. using smaller FOV or field size
20%	5. using compensating filters

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Keeping the other factors the same, patient dose (central mean dose) from KV CBCT will be increased with:

1. decreasing the kV/mAs settings
2. scanning thinner patients
3. decreasing the number of projections
4. using smaller FOV or field size
5. using compensating filters

answer is (2)

Refs:

Islam M, Purdy D, et al. 2006 Patient dose from kilovoltage cone beam computed tomography imaging in radiation therapy *Med Phys.* 33(6):1573-82
Graham MA, Moseley DJ, et al. 2007 Compensators for dose and scatter management in cone-beam computed tomography *Med Phys.* 34(7):2691-703

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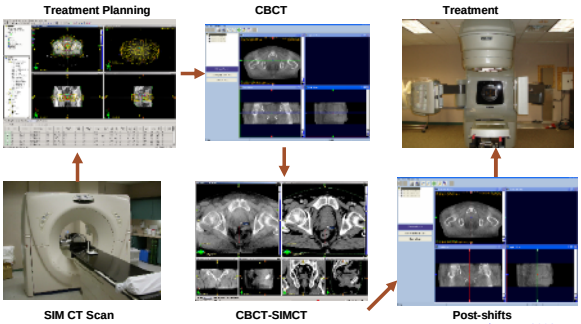
Clinical Protocol for Prostate Cancer



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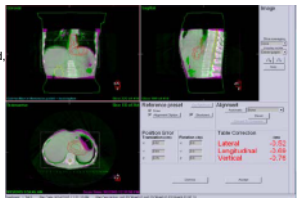
CBCT Imaging Process

- Data Preparation
  - Planning CT with structure set
  - Isocenter information
  - Send via Record Verify System, local load.
- Workflow
  - Select patient
  - Extend arms/gantry starting point
  - Imaging parameters
  - Acquire/reconstruct CBCT
  - Align (bony, soft tissue, VOI)
  - Apply shifts and record
  - Post shifts?
  - Treat
- *Tolerated difference between the planning CT and CBCT depends on image quality, image registration, internal organ motion, margin definitions, user experience which are clinic and anatomical site dependent*



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HU Verification

- The differences in HU values between CT and CBCT for the Catphan were less than 10 HU for most disks materials
- The profiles of CBCT showed lower HU at the periphery (50 to 200 HU)
- CBCT HU from patient data showed lower HU than CT
- The dosimetric consequences (MU/cGy, isodose curves, DVH)) were within 2-3%
- 105% isodose cloud was larger for CBCT lung
- Ares enclosed within the 90% matched very well

Table 1. Comparison of HUs in different tissues of patients

Tissue type	Image	HU ± SD	HU ± SD
Brain cases		Patient A	Patient B
Brain	CT_{Brain}	37 ± 6.8	60 ± 33.2
	CBHFB	84 ± 11.1	54 ± 18.4
Lung cases		Patient C	Patient D
Lung	CT_{Brain}	−965 ± 40.2	−887 ± 191.6
	CBHFB	−978 ± 38.4	−910 ± 82.9
Spine	CT_{Brain}	184 ± 46.8	226 ± 112.5
	CBHFB	110 ± 50.6	218 ± 81.1
Back muscle in the vicinity of the spine	CT_{Brain}	2 ± 46.2	−10 ± 42.8
	CBHFB	−337 ± 74.6	−326 ± 52.0
Prostate cases		Patient E	Patient F
Muscle	CT_{Brain}	67 ± 16.0	65 ± 25.1
	CBHFB	48 ± 34.8	61 ± 54.1
Fat	CT_{Brain}	−90 ± 14.7	−104 ± 16.3
	CBHFB	−112 ± 44.4	−90 ± 43.3
Femoral head	CT_{Brain}	363 ± 65.6	414 ± 95.5
	CBHFB	327 ± 64.5	332 ± 90.1

Yoo S, Yin FF Dosimetric feasibility of cone-beam CT-based treatment planning compared to CT-based treatment planning 2006 Int. J. Radiation Oncology Bio. Phys. 66(5):1553-61

R Hammoud AAPM 2008 CE-Therapy (SAM)

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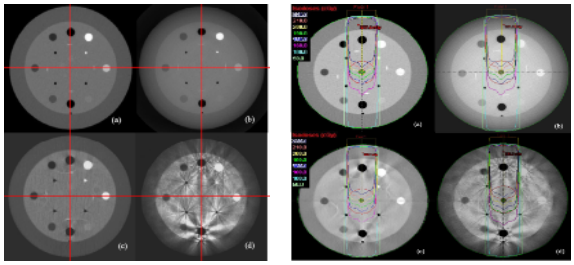
HU Verification



Yang Y et. al. Evaluation of On-Board kV cone beam CT (CBCT) based dose calculation 2007 Phys. Med. Bio. 52:685-705

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HU Verification

- Reference CT maybe different from CBCT (organ deformation)
- Modified CBCT images (mCBCT)
- Dose computed based on the mCBCT was used as a surrogate in the evaluation of CBCT-based dose calculation
- mCBCT possesses the geometric information of the CBCT yet the e- density distribution mapped from the reference CT
- Correspondence between reference CT and CBCT was accomplished utilizing BSIpine deformable image registration software

Yang Y et. al. Evaluation of On-Board kV cone beam CT (CBCT) based dose calculation 2007 Phys. Med. Bio. 52:685-705

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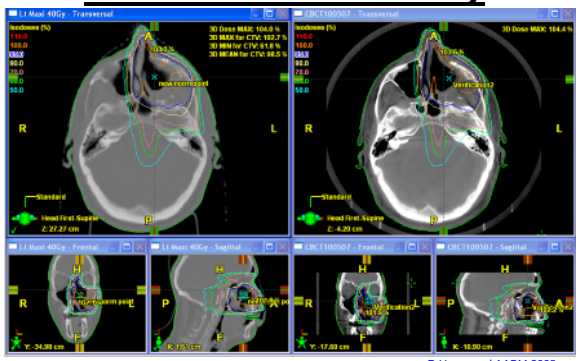
CBCT Brain Maxillary



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PHYSICS CONTRIBUTION

EXAMINING MARGIN REDUCTION AND ITS IMPACT ON DOSE DISTRIBUTION FOR PROSTATE CANCER PATIENTS UNDERGOING DAILY CONE-BEAM COMPUTED TOMOGRAPHY

RABIH HAMMOUD, M.S.,* SAMIR H. PATEL, M.D.,† DEEPAK PRADHAN, M.D.,* JINKOO KIM, M.S.,† HARRISON GUAN, PH.D.,* SHIDONG LI, PH.D.,† AND BENJAMIN MOVSAS, M.D.†

*Josephine Ford Downriver Center for Oncology, Henry Ford Health System, Brownstown, MI; and †Department of Radiation Oncology, Henry Ford Hospital, Henry Ford Health System, Detroit, MI

Purpose: To examine the dosimetric impact of margin reduction and quantify residual error after three-dimensional (3D) image registration using daily cone-beam computed tomography (CBCT) for prostate cancer patients.

- To examine the dosimetric impact of margin reduction from 10/6 to 5/3 for prostate patients undergoing daily CBCT
- Use plan from Reference CT overlaid onto CBCT
- Quantify residual error after 3D image registration

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QA Program

- Safety
- Geometric accuracy (isocenter, accuracy of shifts)
- Image Quality
- Software/ data management

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Geometric Calibration

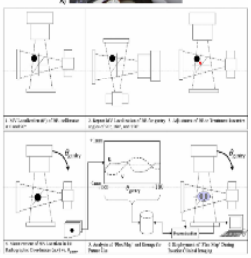
3 isocenters to characterize

1. Mechanical isocenter
2. Radiation isocenter
3. Imaging isocenter

Portal images and CBCT images of ball-bearing (BB) mounted on micrometric stage

Location of the BB is detected from each projection and the apparent trajectory of the BB in the U V directions is plotted again gantry angle

Flexmap describing the discrepancy between the mechanical isocenter and the volumetric imaging system and the radiation isocenter (corrected reconstructed software, compensated by servos in the robotic arms)



Bisonnette JP, Moseley D et. al. Quality assurance for the geometric accuracy of cone-beam CT guidance in radiation therapy Int. J. Radiation Oncology Bio. Phys. 71(1):S57-S61

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A quality assurance program for the on-board imager®

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Med. Phys. 33 (11), November 2006

OBI: Daily QA

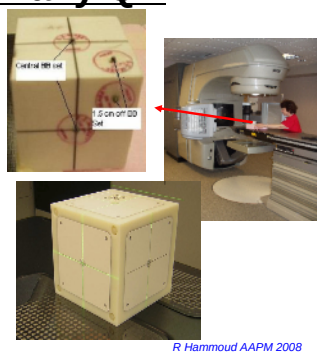
Daily QA procedure checks the geometric accuracy of the OBI system by performing the following tests:

Test 1: Tube/detector positioning accuracy

Assures that the imagers (MVD &KVS/KVD) isocenter matches the LINAC isocenter

Test 2: Matching and couch motion accuracy

Positional differences detected by the OBI workstation can be reliably transferred to couch motion

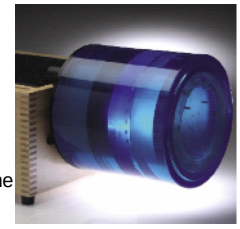


Safety QA

- **Interlocks (motion disabled)**
- **Door interlocks**
- **Tube warm up**

Annual CBCT QA

- Mechanical checks (geometric calibration)
- Imaging dose (mA, HVL,..)
- Image quality
  - Scaling/distance (0.5 mm tolerence)
  - CT number uniformity-basline established
  - spatial resolution- baseline
  - Low contrast resolution-baseline



Which of the following tests you would consider the least performed on monthly basis for On-Board Imaging QA procedure:

20%	1. safety
20%	2. imaging dose
20%	3. geometric accuracy
20%	4. image quality
20%	5. data storage capacity

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Which of the following tests you would consider the least performed on monthly basis for On-Board Imaging QA procedure:

1. safety
2. imaging dose
3. geometric accuracy
4. image quality
5. data storage capacity

answer is (2)
Ref:
Yoo S, Kim G, Hammoud R, et al. 2006 A quality assurance program for the on-board imagers *Med Phys.* 33(11):4431-47

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Summary

- Scatter is the major issue in CBCT image quality
- Many commercial products have been introduced improving the image quality of CBCT
- Imaging dose: decreasing the exposure, number of projections, filters, algorithms
- Though dose calculated on CBCT agree with reference CT dose for some clinical sites (prostate), it is not recommended to replace the conventional CT with CBCT (inferior image quality to delineate tumor and critical structure, limited FOV)
- Several publications addressed QA guidelines.

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Thank you