kV- & MV-CBCT Imaging for Daily Localization: Commissioning, QA, Clinical Use, & Limitations

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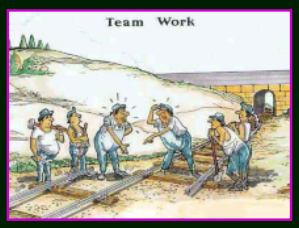
Team Work



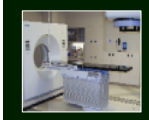
Olivier Gayou
Bodo Reitz
David Parda
Physics & Clinical Staff

Siemens Medical Solutions

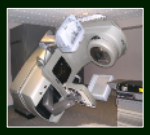
In RT, We Ask the Questions

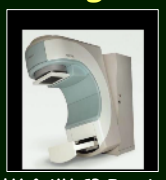
- Disease Stage (local, regional, metastatic)
- Tumor location
- Edge of the tumor volume
- Nodes involvement
- Tumor within Rx fields
- OARs location
- Modulate the intensity to maximize the therapeutic ratio

In-Room Imaging Technologies


CT on rails


2D kV Imaging

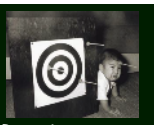

kV CB Imaging


kV & MV CB Imaging


kV CB Imaging


MV-CT Imaging

CBCT Imaging in a Nut Shell



- Imaging of the tumor and surrounding OARs prior to Rx
- Physicians can immediately compare Rx images to planning CT images to ensure accurate Rx delivery
- CBCT provides a 3D image of the tumor, so its depiction is more accurate and precise than with traditional 2D images
- CBCT allow us to refine the treatment plan during the course of treatment to adapt to changes in the tumor's size

Mega-Voltage CBCT

- MV-CBCT features & characteristics
- The image quality vs. exposure challenge…
- … and an elegant workaround
- MV-CBCT as a localization system
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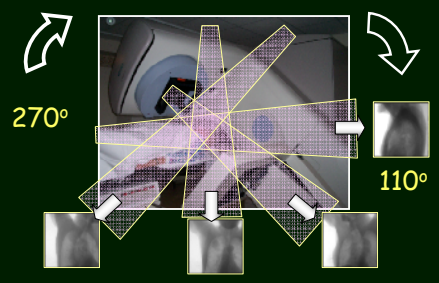
- Conclusions

MV-CBCT Basics

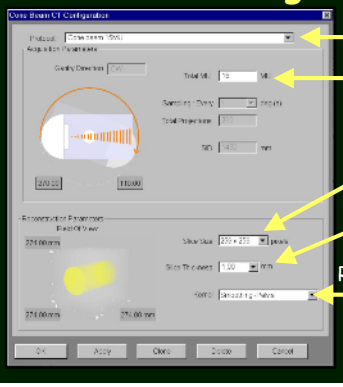


3, 5, 8, 10, 12, & 15 MU delivery protocols (0.01-0.1 MU per projection)

Characteristics of MV-CBCT

- Volumetric patient image using a 6x beam
- High sensitivity a-Si panel
- Synchronization of beam pulse & panel read out
- Gantry rotation of 200 degrees
- Time: acquisition ~ 50 sec & recon. ~ 1 min
- 27 cm^3 max FOV (FS 27.4 x 27.4 cm & SID @ 145 cm)
- Slice thickness range: 1 mm to 5 mm
- CT image sizes: 128^2, 256^2 or 512^2 pixels
- Dose delivered 3 cGy – 12 cGy

MV-CBCT Configuration



CB Protocol Name

MUs (1-200)
4, 10, 15 MU

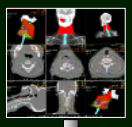
Slice Size: 128x128, 256x256, 512x512

Slice Thickness
0.5 to 10 mm

Reconstructing Kernel:
Smoothing,
Smoothing H&N,
Smoothing pelvis

MV-CBCT Work Flow

Planning CT



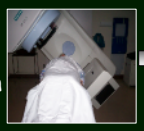
Treatment Plan

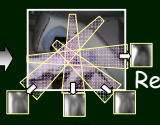
Localization

TX Delivery

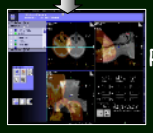
MV-CBCT Localization

Acquisition



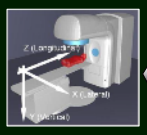


Reconstruction



Registration

Table offsets



4-6 minutes

An Integrated System

Image Registration

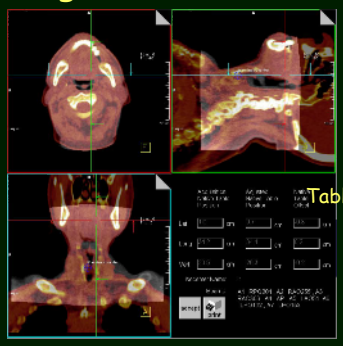


Table offsets

Planning CT and CBCT

Mega-Voltage CBCT

- MV-CBCT features & characteristics
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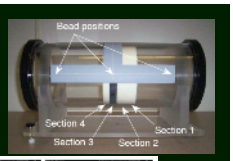
Image Contrast vs. Exposure



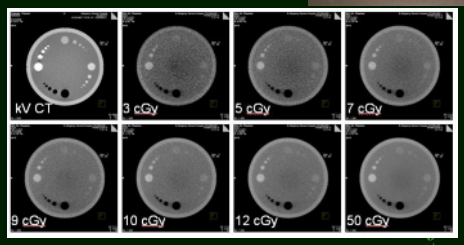
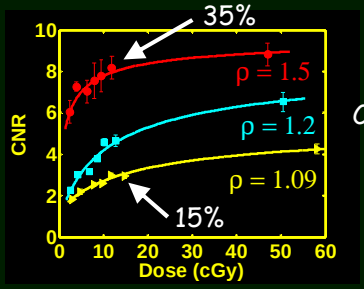


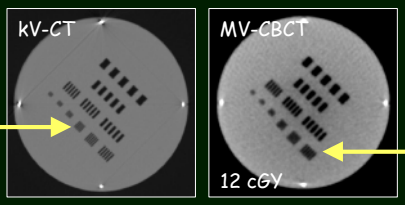
Image Quality Phantom

CNR vs. Dose for 7 MU Protocols and 3 Materials



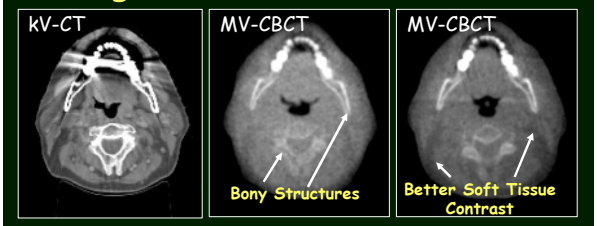
CNR ~ √dose

Resolution vs. Exposure



- Smallest visible bar group was 0.3 lp/mm for the 3 & 5 MU protocols
- 0.4 lp/mm for all other protocols.
- kV-CT was 0.6 lp/mm

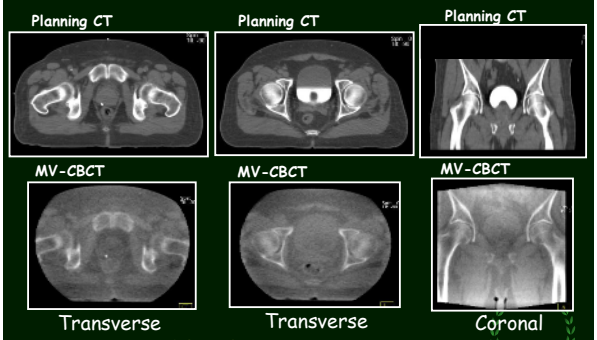
Improved Contrast & Resolution at Higher Doses But…



2.5 cGy 9 cGy

Sufficient bony anatomy at 2.5 cGy

Prostate Patient



10 cGy at isocenter

Dose Verification & Simulation

Phantom Diam.	16 cm		32 cm	
MU Protocol	10 MU		15 MU	
Method	Meas	Calc	Meas	Calc
Isocenter	7.9	8.1	9.2	9.3
0°	10.3	10.2	12.1	11.6
90°	8.9	8.7	9.7	9.5
180°	6.9	7.1	4.1	4.1
270°	8.3	8.3	8.2	8.1

Chamber Measurements

TLD Measurements

Measurements and calculations are within 0.5 cGy

Gayou, Parda, Johnson, and Miften, Med Phys 34, 499-506 (2007)

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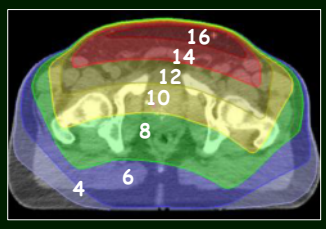
Imaging CB Dose Distributions

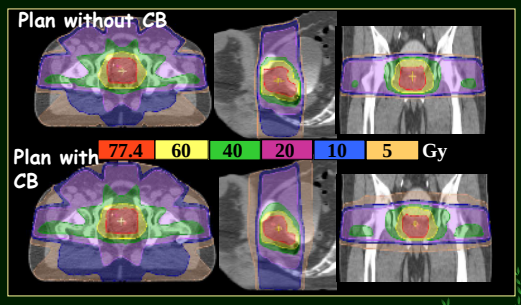


Dose in cGy

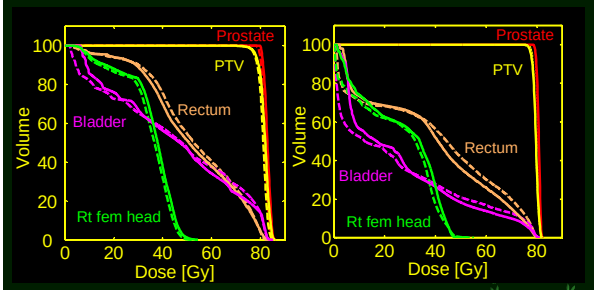
15 MU Protocol

Model the CB imaging beam as an arc beam

IMRT Incorporating Dose from MV-CBCT



DVHs w & w/o MV-CBCT



Patient A

Patient B

Miften, Gayou, Reitz, et al, Med Phys 34, 3760-3766 (2007)

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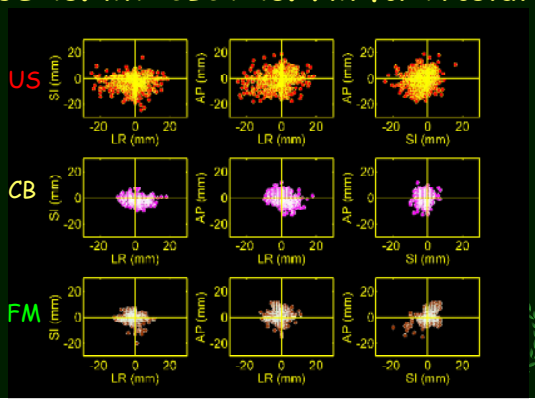
US vs. MV-CBCT vs. FM for Prostate

US: 696 couch alignments for 19 patients

CBCT: 598 couch alignments for 17 patients

FM: 393 couch alignments for 12 patients

US vs. MV-CBCT vs. FM for Prostate



Prostate Systematic & Random Errors

Localization method	AP (mm)	LR (mm)	SI (mm)	3D shift (mm)
US	-1.0 ± 5.9	-1.2 ± 6.8	-2.8 ± 5.1	8.8 ± 6.2
MV-CBCT	-0.3 ± 3.9	1.0 ± 3.9	-1.3 ± 2.5	5.3 ± 3.4
FM	0.5 ± 4.1	-1.0 ± 3.4	0.0 ± 3.4	5.2 ± 3.7

Percentage of Shifts Greater than 5 mm

Prostate PTV Margins

van-Herk formula: $M=2\Sigma+0.7\sigma$

→ US data: 12.4 mm

→ CB data: 8.2 mm

→ FM data: 8.5 mm

Localization Method	AP	LR	SI
US	38%	34%	31%
MV-CBCT	16%	18%	6%
FM	10%	14%	10%

Gayou and Miften, Med Phys 35, 531-538 (2007)

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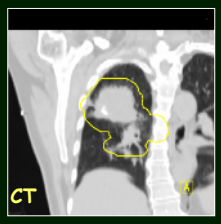
MV-Cine

- Camera moving around patient
- Data from MV-CBCT is used as fluoroscopic series of portal images to monitor changes on short time scales (e.g. tumor motion)

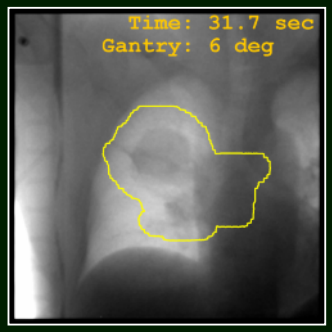
Individualized, adaptive treatment margins

MV-CBCT: Ave Scan Over Time



- NSCLC, right Upper Lobe, Stage IIIA T2 N2 M0
- MV-CBCT well suited for localization of tumor, but does NOT show tumor motion

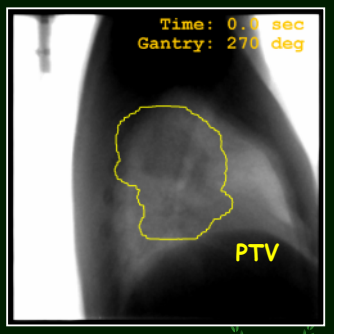
Full Breathing Cycle w/MV-Cine



- Consecutive projections covering one breathing cycle (range 6° – 15°)
- Diaphragm Movement (2cm)
- Tumor mass moves by 1cm

Perspective w/MV-Cine

- Complete MV-cine 270° → 0° → 110° (unlike fluoroscopy)
- Advantage:
  - Quasi 3D view
  - Motion in LR, AP, and SI can be seen



Reitz, Gayou, Parda, and Miften, PMB 53, 823-836 (2007)

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QA Procedures & Frequency

Procedure	Daily	Monthly	2x/yr	Device
Position calibration			✓	PI, reticule
Gain calibration		✓ (2x)		PI
Dead pixel map		✓		PI
EPID image quality	✓	✓		Vegas, PIPSpro
Horizontal pos. accuracy	✓			PI, reticule
Vertical pos. accuracy		✓		Ruler
Geometry calibration			✓	George phantom
CB gain calibration		✓(2x)		CB 15, 60 MU
3D image quality		✓		Ema phantom
Reconstr. & Registration		✓		Ema phantom
Dose		✓		Ion chamber

Gayou and Miften, Med Phys 34, 3183-3192 (2007)

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MV-CBCT Imaging Numbers

- MVision in clinical use since June 06
  - An upgrade on a Primus Linac
  - First patient was imaged on 6/5/06
- 226 Patients; ~ 4000 CBCT scans
  - H&N and Brain: 54
  - Lung/Thorax: 47
  - Spine: 5
  - Prostate: 37
  - Prostate Bed: 17
  - GI/GU: 66
- Total Downtime: 3 days

Which Patients Should be Imaged with CB?

- Tumors adjacent to critical structures
- Tumors prone to inter-fractional motion
- Tumors with intra-fractional motion- (Preference: 4-D planning)
- Tumors prone to deformation
- Compliant patients

CBCT: Clinical Responsibilities

- Physician
  - ✓ Determine clinical indication(s)
  - ✓ Order CBCT
  - ✓ Determine frequency
  - ✓ Review images (day 1, twice/weeks, daily??)
  - ✓ Define primary ROI for physicist/therapist
  - ✓ Define set up parameters
  - ✓ Review daily shifts

CBCT: Clinical Responsibilities

- Physicist-
  - Available to review images & shifts daily
  - QA, calibration, output, image quality…etc
- Dosimetrist –
  - Dose incorporation
- Therapist -
  - Review images
  - Make appropriate table shifts

Ordering a CB for a Patient

Physician	Daily, twice/wk, weekly	← Frequency
Physician	Soft-tissue or bony anatomy	← Registration
Physicist	Imaging protocol 4 MU or 8-15 MU	← Exposure
Physicist Therapist	Physician by machine console for 1st Rx	← Review & Thresholds

Conclusions

- MV-CBCT is a viable technique for treatment localization
- Observed inter-fractional variations are patient specific and site-dependent
- Application of MV-CBCT for daily localization with good-image quality
- Application of MV-CBCT for verification of intra-fractional motion immediately prior to treatment delivery

SAM: Question 1

The contrast-to-noise ratio (CNR) in MV-CBCT images is proportional to

25%	1. dose
25% ➡	2. √dose
25%	3. 1 / dose
25%	4. 1 / √dose

10

SAM: Question 2

MV-CBCT images with improved contrast and high resolution are achievable with doses ≥ 6 cGy and sufficient bony anatomy is <u>feasible</u> at doses

25%	1. > 5 cGy
25%	2. < 0.5 cGy
25%	3. < 1 cGy
25% ➡	4. ~ 2.5 cGy

10

SAM: Question 3

With MV-CBCT imaging, the anatomical region in patients receiving maximum imaging dose exposure is located

25%	1. anteriorly near the surface
25%	2. posteriorly
25%	3. isocenter
25%	4. mid-plane

10

Thank you