Daily Localization:

MV Cone-Beam CT

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Course Objectives

1. Understand the basics of MV Cone-Beam CT imaging

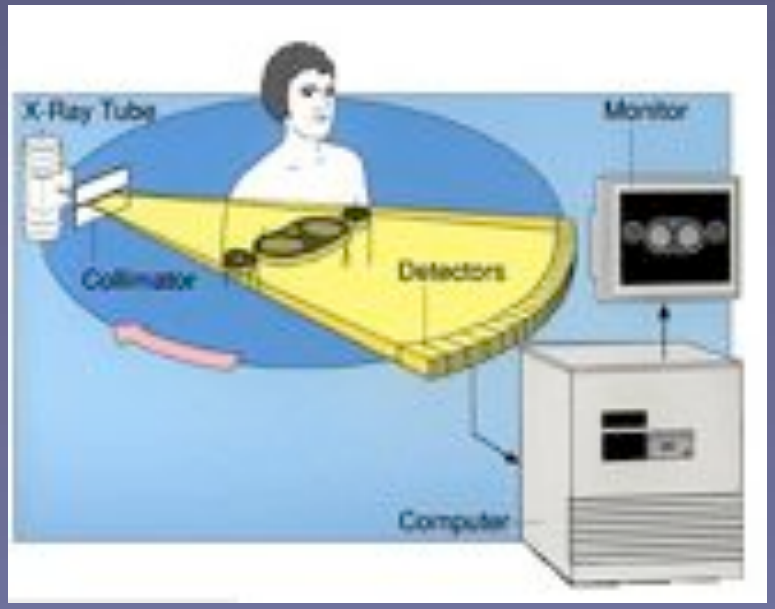
2. Understand the possibilities of daily 3D Imaging for patient alignment and other applications

3. Understand the clinical roles of Image-Guided (IGRT) and Dose-Guided (DGRT) Radiation Therapy

- Description of MVCBCT
  - Fan Beam vs Cone Beam
  - Basic Principles and Characteristics
  - Image Samples
- Workflow of IGRT with MVCBCT
  - Acquisition, Reconstruction & Registration
  - Absolute Positioning & Alignment Presicion
- Clinical Applications
  - Patient positioning
  - Monitoring of anatomical changes
  - Target delineation with CT non-compatible objects
  - Tomosynthesis, Brachytherapy, etc.
  - Dose calculation to assess dosimetrical impact
- Dose-Guided Radiation Therapy

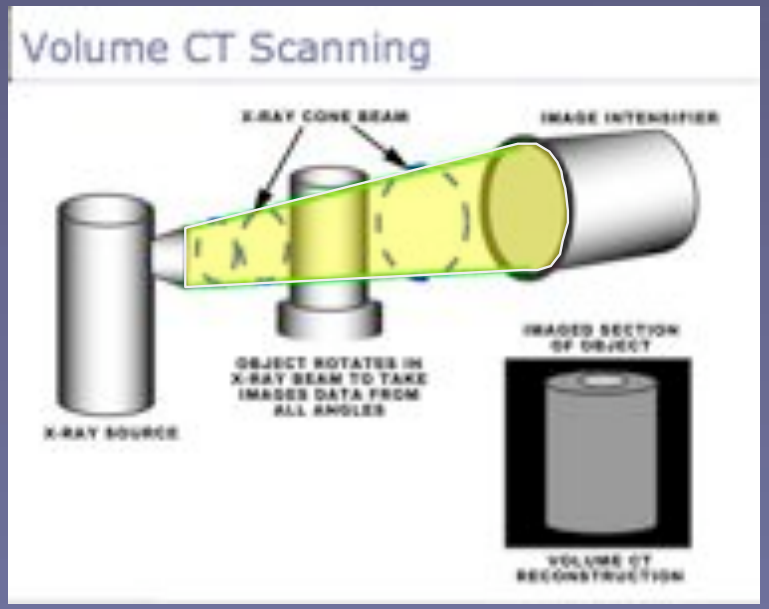
Basic Principles of MV CBCT

Fan beam CT



1 slice per rotation

Cone-beam CT

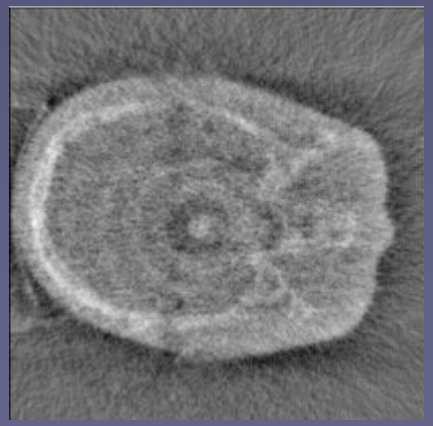


Entire volume in 1 rotation

Basic Principles of MV CBCT

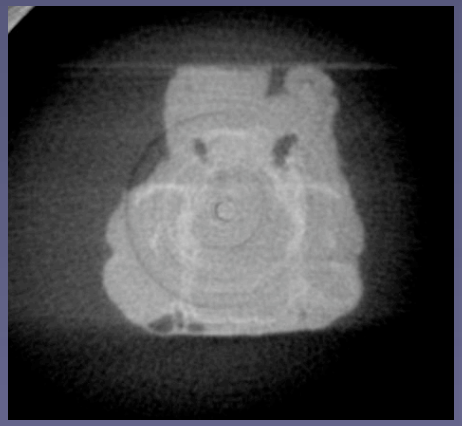
- MVision™ generates a 3D image of the patient anatomy from the same x-ray beam (6MV) used for treatment.
- Image and x-ray beam share the same isocenter.
- Patient 3D anatomy in treatment position, moments before dose delivery.

2001



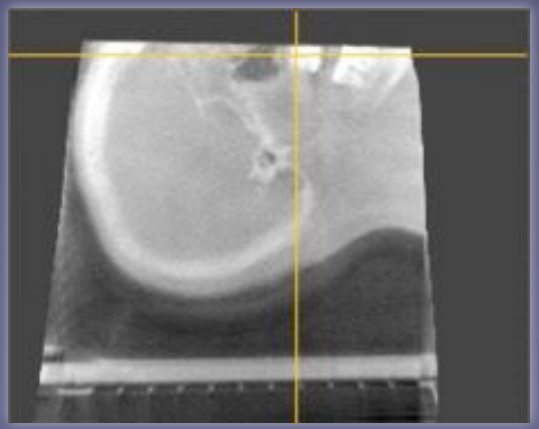
21 MU

2002



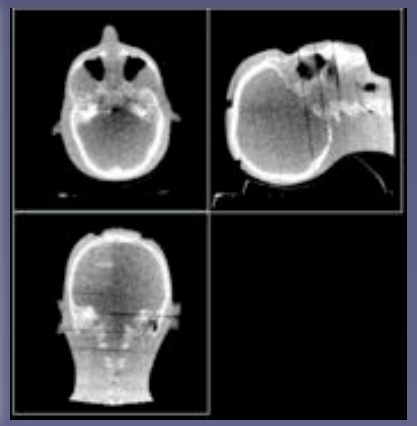
16 MU

2003



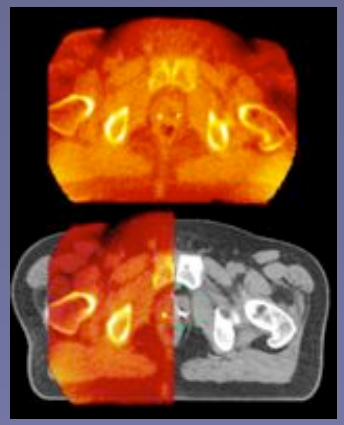
16 MU

2004



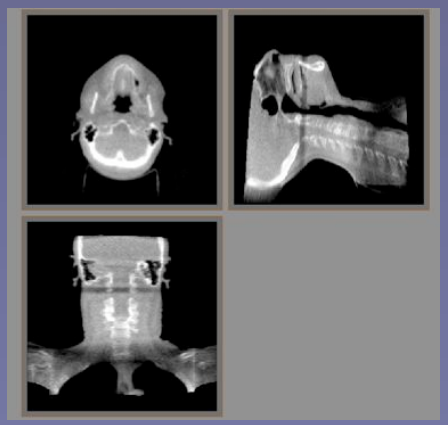
1 MU

2004



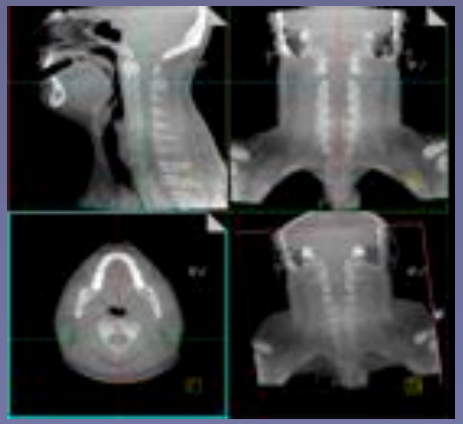
15 MU

2005



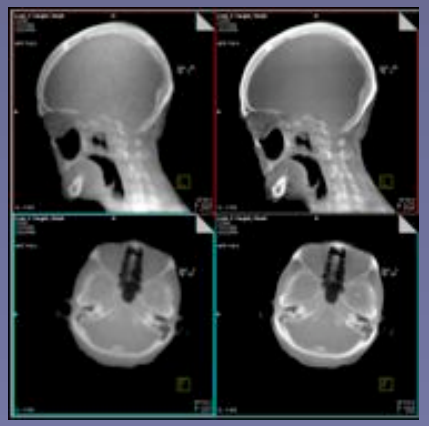
10 MU

2006



6 MU

2007



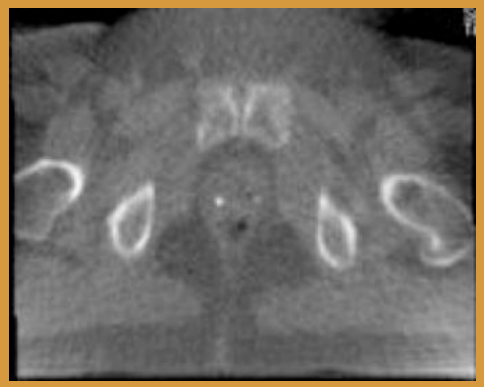
1-2 MU ?

On Board CT

MV CT

Courtesy of K. Langen

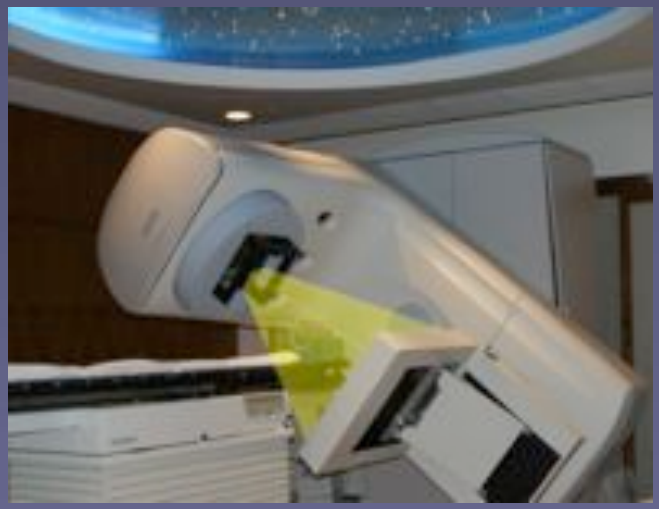
MV CB CT



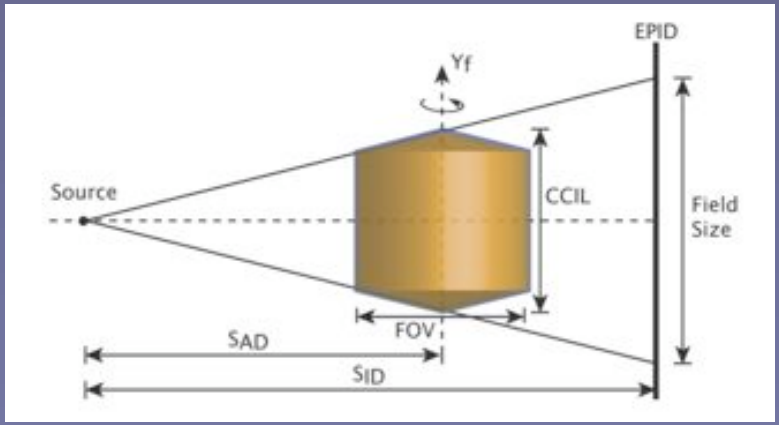
kV CB CT

Courtesy of F.F. Yin

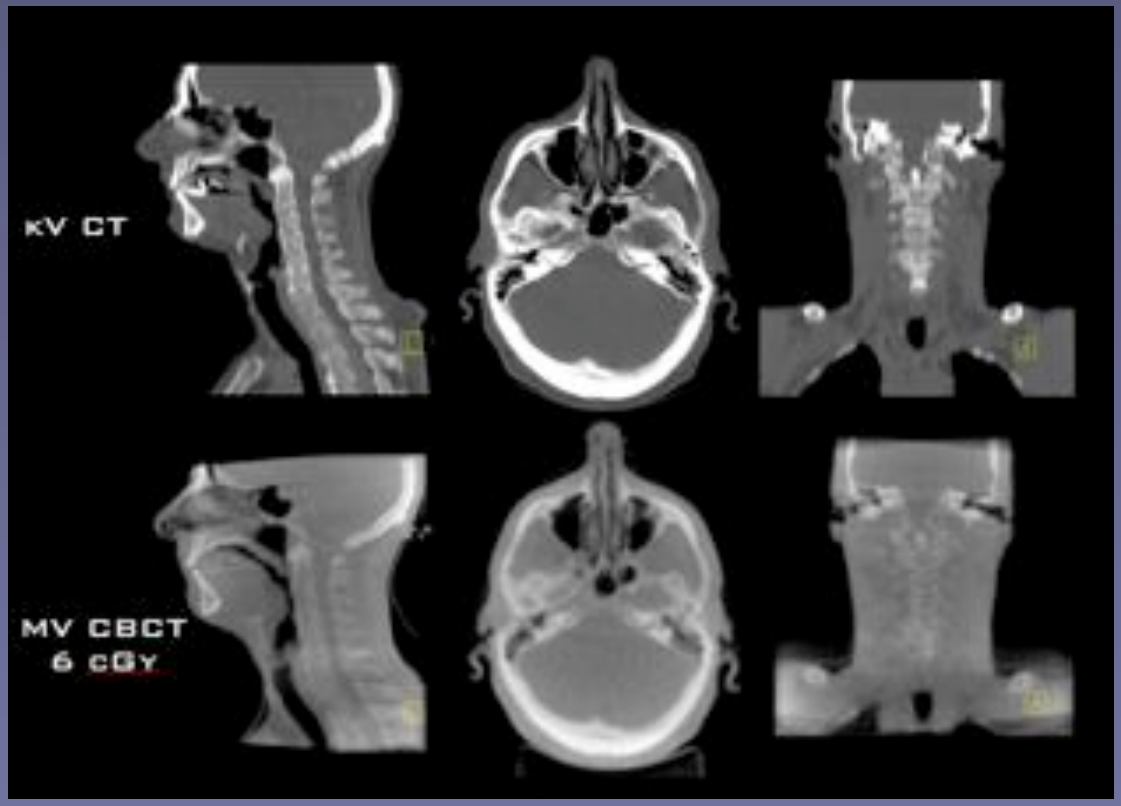
Basic Characteristics of MV CBCT

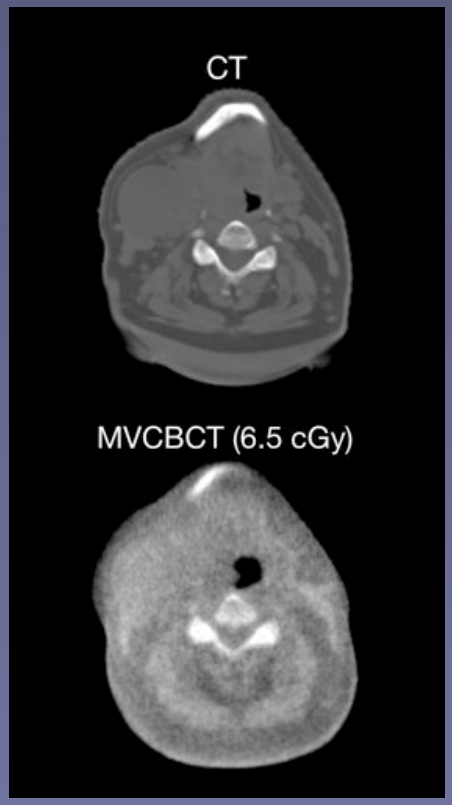


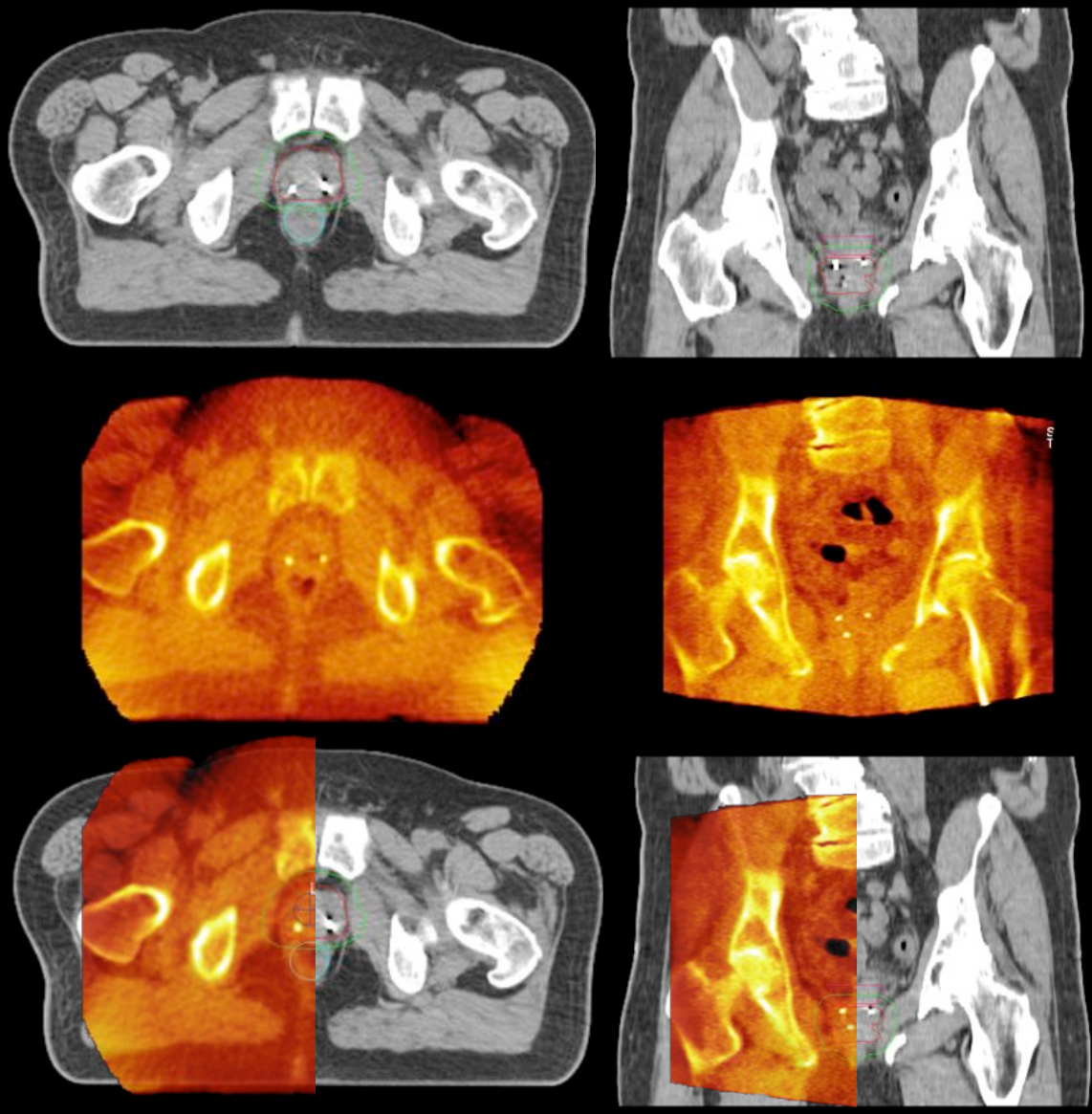
- Half rotation: 200 degrees
- Acquisition ~ 45 seconds
- Acquisition + Reconstruction < 2 min.
- 27 cm x 27 cm x 27 cm Field of View
- Volume of 256 x 256 x 270
- Pixel size $(0.5\ mm)^3$
- Typical dose: 2 to 9 cGy
- Accurate Electron Density



MV CBCT







Prostate

Dose from Imaging

		RBE	
MV CT:	< 2 cGy	.... x 1	< 2 cSv
kV CBCT$_1$:	< 4 cGy	.... x 1.8 to 4	< 7 cSv
MV CBCT:	< 9 cGy	.... x 1	< 9 cSv
kV CBCT$_2$:	< 12 cGy	.... x 1.8 to 4	< 21 cSv

- Islam M. et al., **Patient dose from kilovoltage cone beam computed tomograhy imaging in radiation therapy**, Med. Phys. 33 (6), pp1573-1582, June 2006.
- Wen. N., **Skin and dose measurement measurement for Cone-Beam CT during IMRT for prostate patient**, TH-D-ValB-02
- Hendee WR, Ritenour ER. Medical Imaging Physics, Fourth Edition. NewYork: Wiley-Liss; 2002.
- Morin et al., **Patient Dose Considerations for Routine Megavoltage Cone-Beam CT Imaging**, Med. Phys. 34(5), 1819-1827; 2007.
- Meeks SL et al., **Performance Characterization of megavoltage computed tomography imaging on a helical tomotherapy unit**.
- Wen N, Guan H, Hammoud R, *et al*. TH-D-ValB-02: **Skin and Body Dose Measurements for Varian Cone-Beam CT (CBCT) During IMRT for Prostate Cancer**. Med Phys 2006;33:2280.
- Hill M.A., **Variation in Biological Effectiveness of X-Rays and Gamma Rays with Energy**, Radiation Protection Dosimetry (2004), Vol. 112, No. 4, pp.471-481

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  - Image Samples
- Workflow of IGRT with MVCBCT
  - Acquisition, Reconstruction & Registration
  - Absolute Positioning & Alignment Presicion
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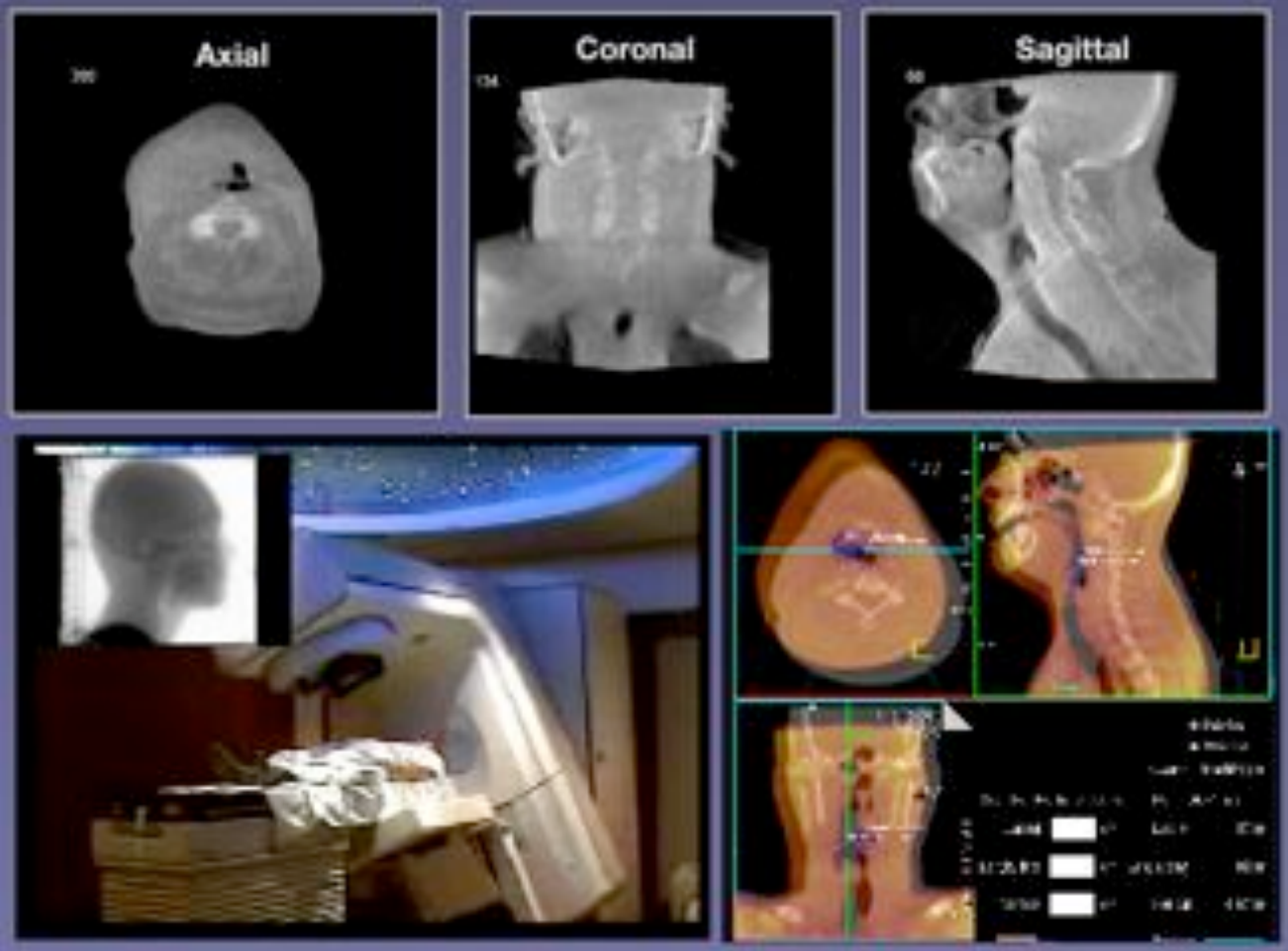
Workflow of IGRT with MV CBCT

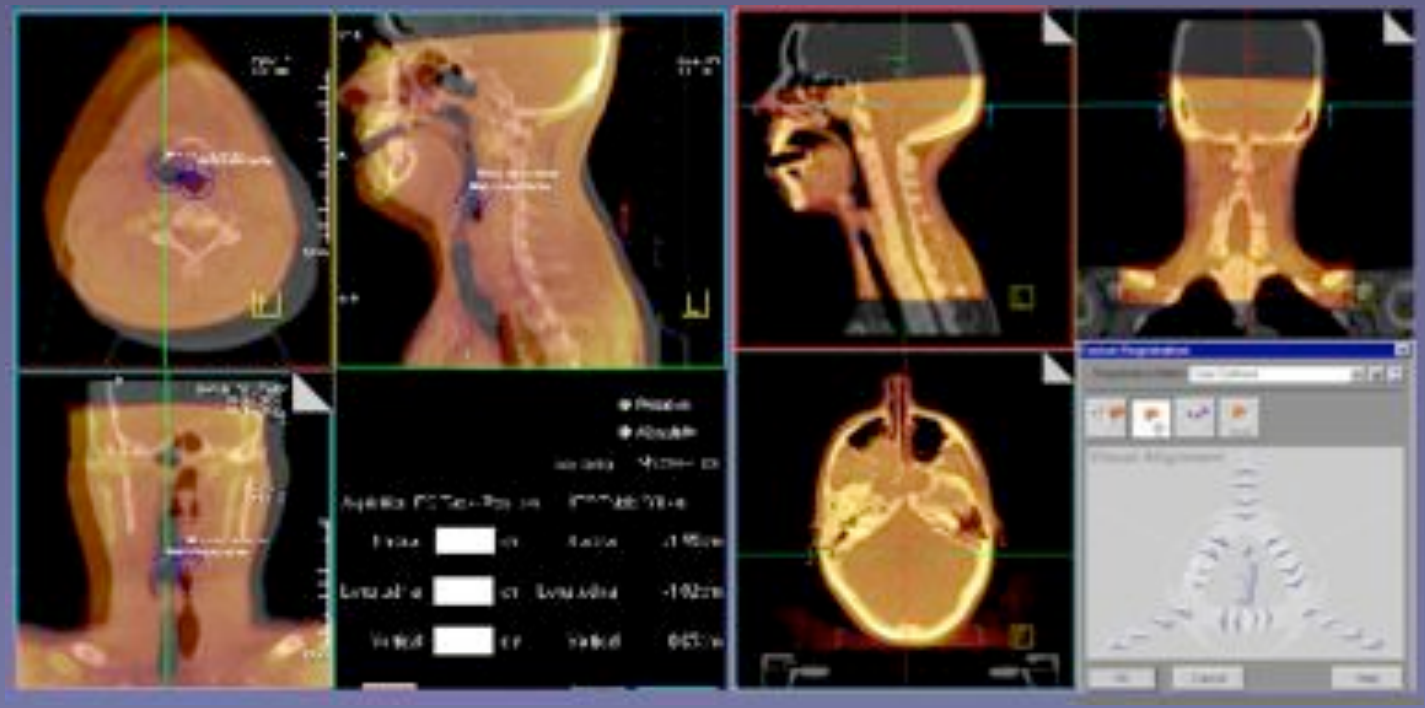
- 1) The patient and the cone-beam acquisition mode are selected at the treatment console.
- 2) The linac gantry is placed in starting position, namely 270 degrees.

MV Cone-Beam CT Acquisition and Reconstruction

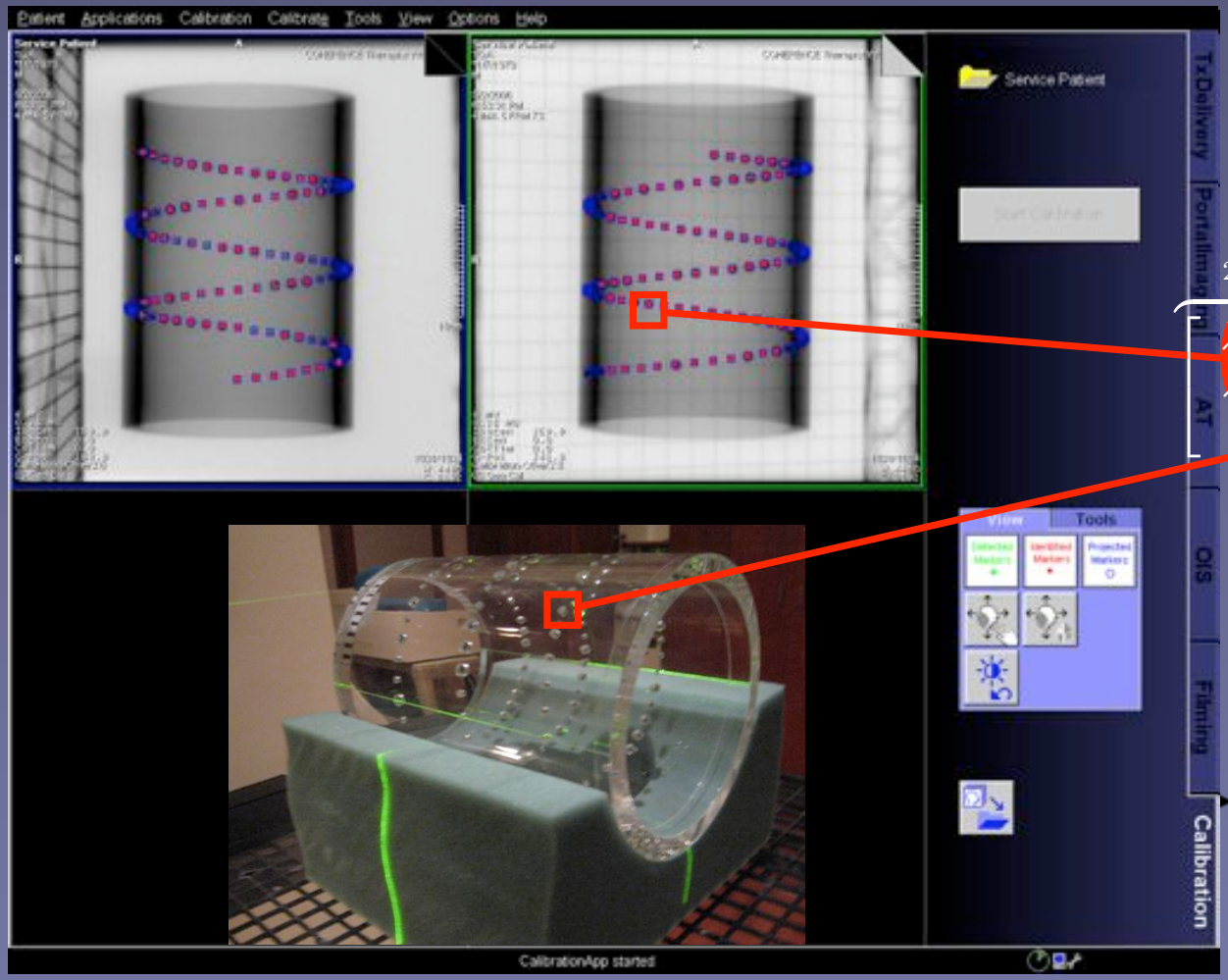


MV CBCT - CT Registration

4) Upon completion of the reconstruction image, the cone-beam image is automatically loaded in the Adaptive Targeting Sofware™, and the CB to CT image registration is performed automatically in few seconds using a mutual information algorithm.



Geometric Calibration



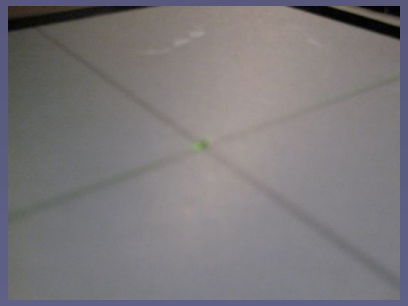
$$\vec{p} = P_{mat} \cdot \vec{P}$$

$$\overbrace{\begin{bmatrix} \lambda u \\ \lambda v \\ \lambda \end{bmatrix}}^{2D} = [P_{mat}]_{3\times 4} \overbrace{\begin{bmatrix} X \\ Y \\ Z \\ 1 \end{bmatrix}}^{3D}$$

$$[P_{mat}(\theta)]_{3\times 4}$$

Reconstruction Program

Absolute positioning

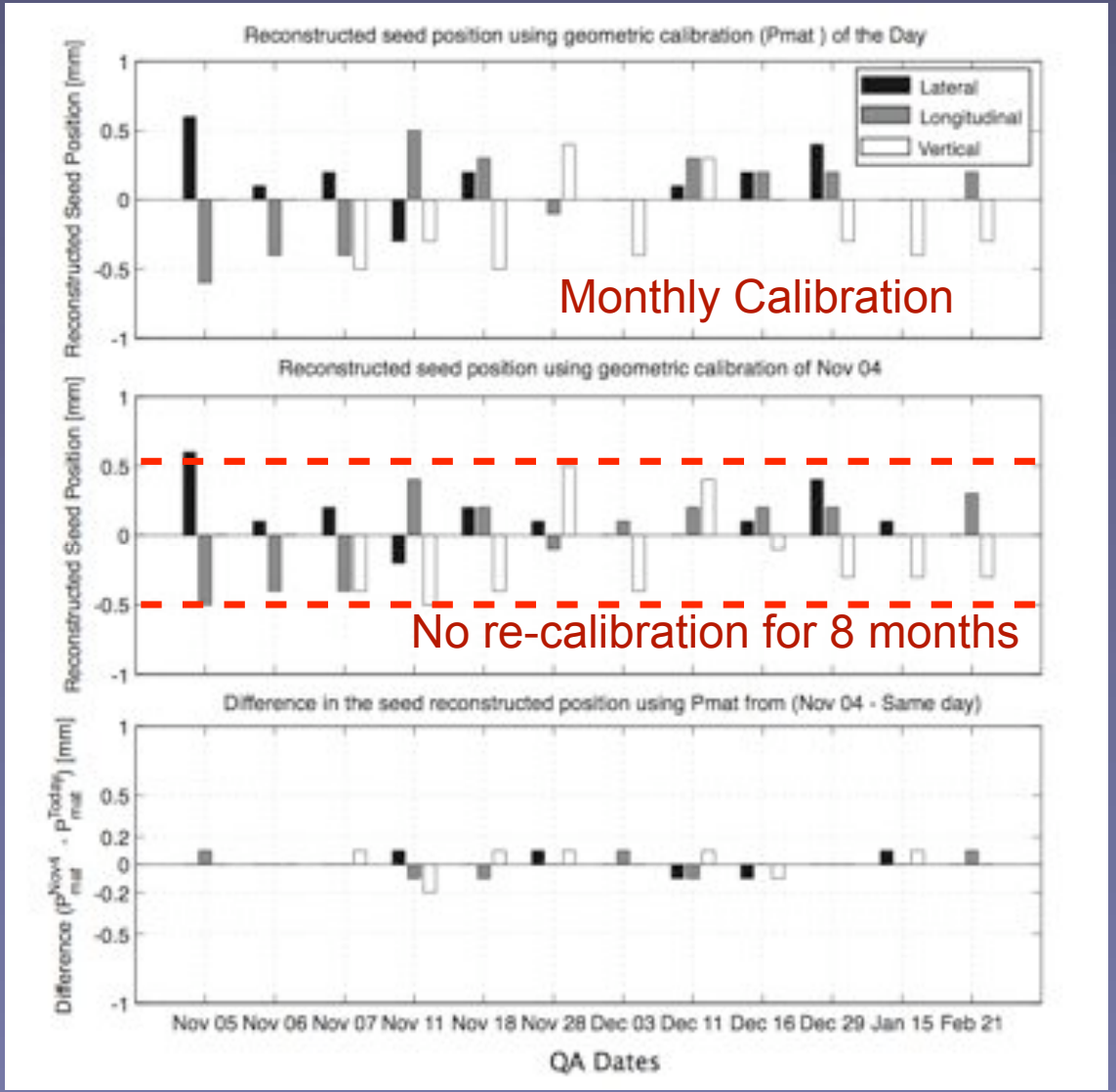


1) Place a small fiducial marker at isocenter

2) MV CBCT Imaging

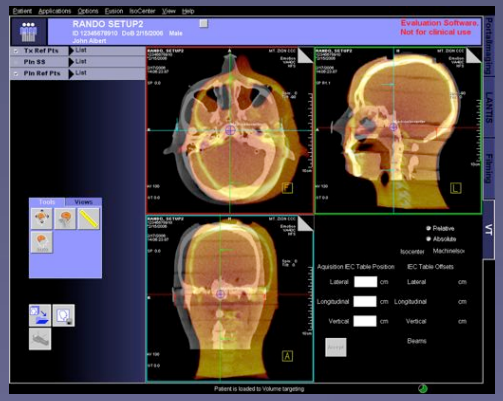
3) Verify position of the fiducial in the reconstruction space

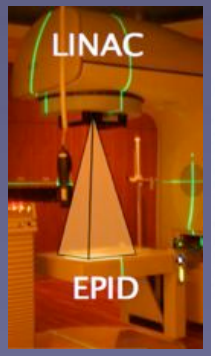
Should be: [-0.1, 0.1] cm

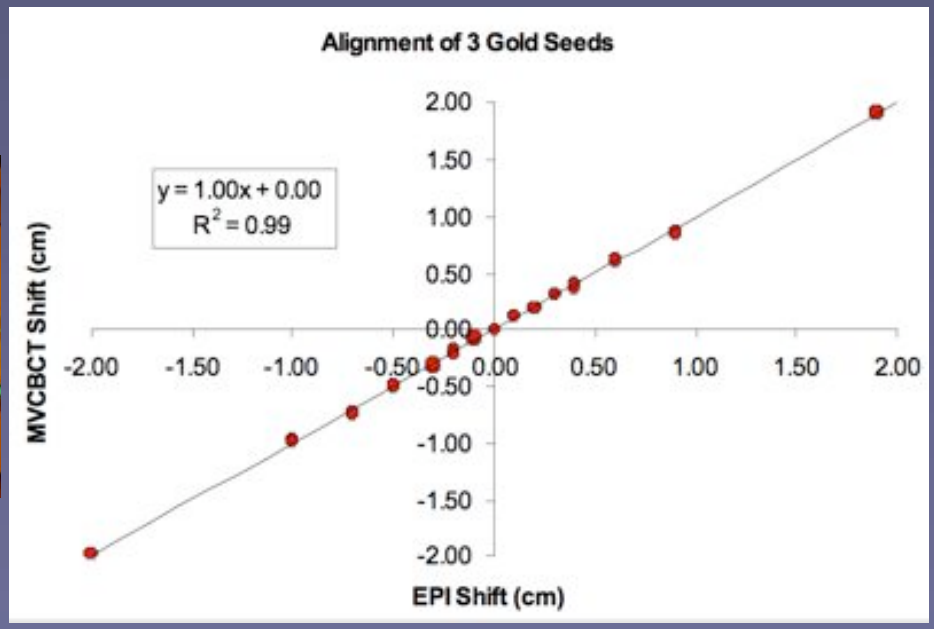


2D (EPID) vs 3D (MVCBCT) Setup Methods

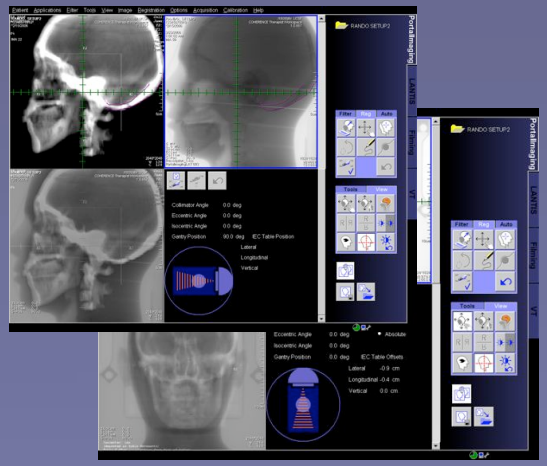
3D method: CT with MV CBCT

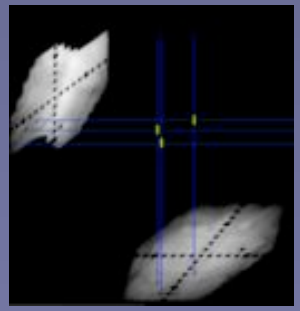






2D method: DRR with EPI





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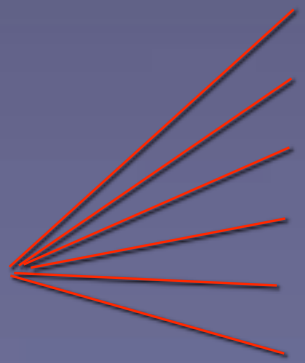
Patient positioning



- Head & Neck
- Lung
- Spine
- Chest
- Breast
- Prostate

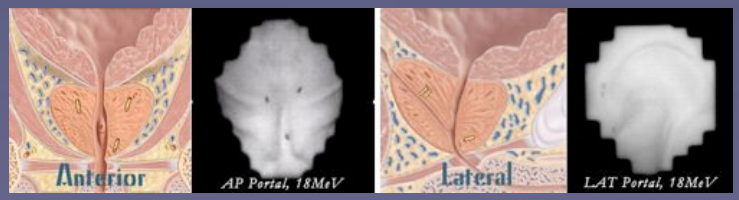
Acquisition Protocols

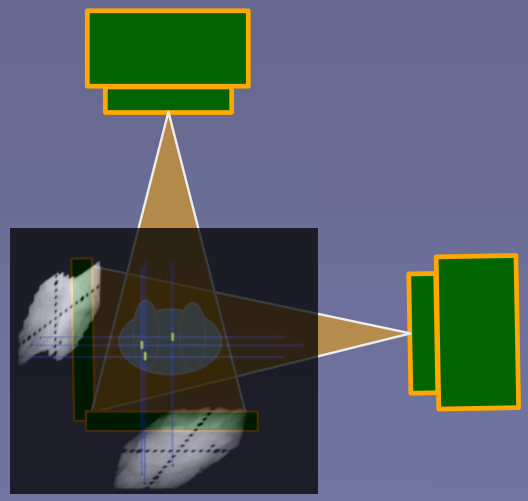
	Patient Alignment *Daily or weekly imaging*	Planning or DGRT *Imaging once or twice*
Head and neck	Exposure (MU): 5-8 (bone). Recon Size: 256 x 256 Slice Thickness: 1 or 3 mm FOVz: exclude eyes if possible Kernel: Smoothing -H&N	Exposure: 10-20 MU Recon Size: 512 x 512 Slice Thickness: (1) to 5 mm* FOVz: exclude eyes if possible Kernel: Smoothing -H&N
Chest or Breast	Exposure (MU): 5-10 (bone). Recon Size: 256 x 256 Slice Thickness: 1 mm FOVz: full length Kernel: Smoothing -Pelvis	Exposure: 15-20 MU Recon Size: 512 x 512 Slice Thickness: (1) to 5 mm* FOVz: full length Kernel: Smoothing -Pelvis
Pelvis	Exposure (MU): 3-4 (seeds), 4-7 (bone), 8-12 (soft-tissue). Recon Size: 256 x 256 Slice Thickness: 1 mm FOVz: full length Kernel: Smoothing -Pelvis	Exposure: 15-20 MU Recon Size: 512 x 512 Slice Thickness: (1) to 5 mm* FOVz: full length Kernel: Smoothing -Pelvis

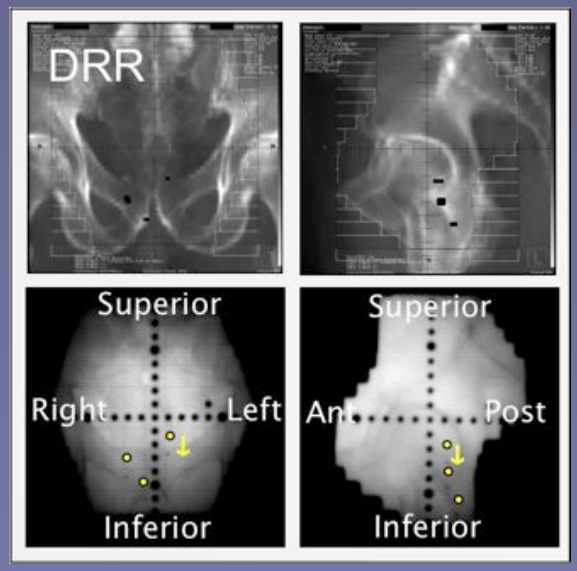
* Best to reconstruct with 1 mm slice thickness and resample images to 3 or 5 mm for planning applications. 1 mm will produce too many slices for most planing systems.

Daily Prostate Alignment
EPID + Markers

- Patient alignment with gold markers since 1994
  - **Off line verification (1997)**
  - **On line verification (Daily alignment since 2001)**
  - **> 800 patients -> Clinical routine**







Prostate Motion Management at UCSF
EPID + Markers

- Accuracy (Aubin et al. 2002): . . . . . Global accuracy ~ 1.5 mm
- Patient tolerance to implant (Downs et al. 2002): . . . .Side effects < biopsy
- BAT vs. EPID (Langen et al. 2003): . . . . . User variability
- Visibility of Markers (Aubin et al. 2003): . . . . . 1 x 3 mm
- Migration & Positional Stability (Pouliot et al. 2003): . . . . . sigma ~ 1.3 mm
- Obese patients (Millender et al. 2004): . . . . . Patient setup > organ motion
- Post-Prostatectomy (Schniffer et al. 2005): . . .Prostate bed moves, but less
- Long-term f-up w/ MRS (Pickett et al. 2006): . . . Shorter metabolic atrophy
- Intra-fractional motion (Lometti et al. 2006): . . . . . Minutes, not seconds
- Dual Target Adaptive Strategy (Xia et al., 2007): . . . Lymph nodes Boost

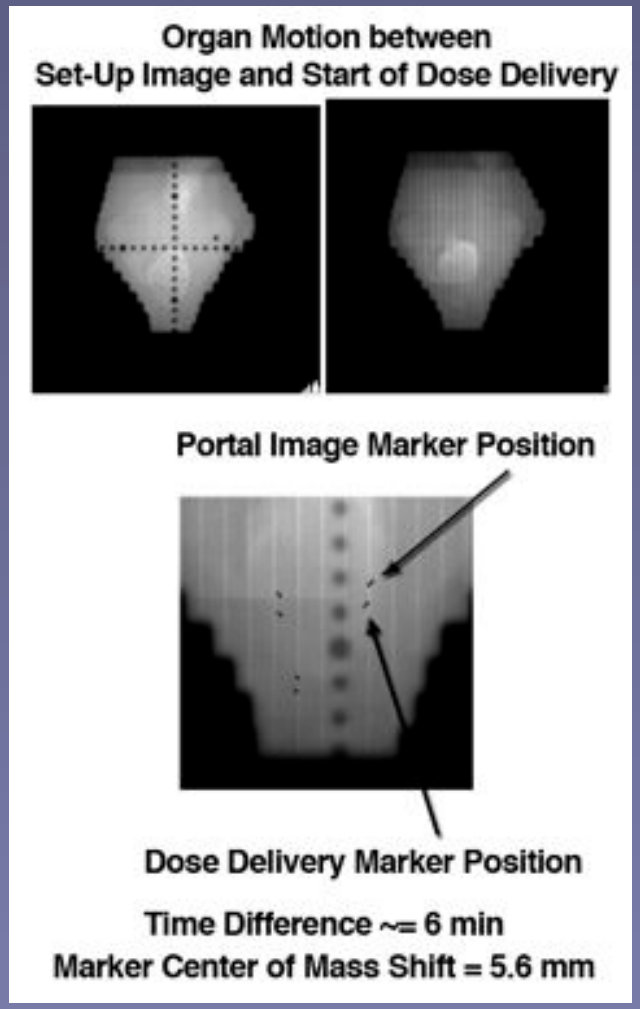
MVCBCT Acquisition -Pelvis

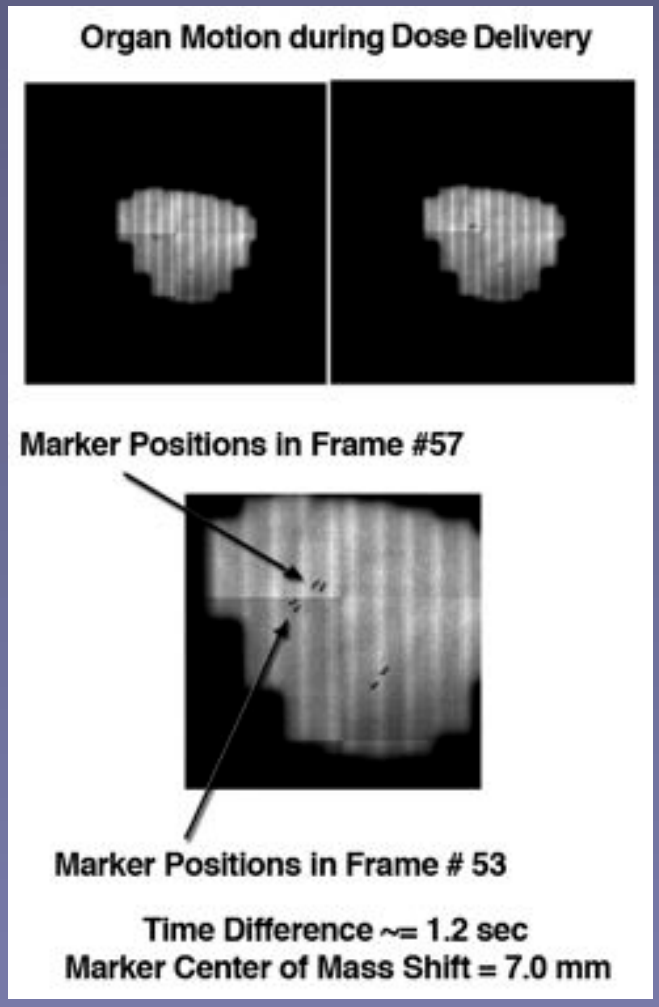
SUPERIOR

INFERIOR

Intra-Fractional Prostate Motion Study

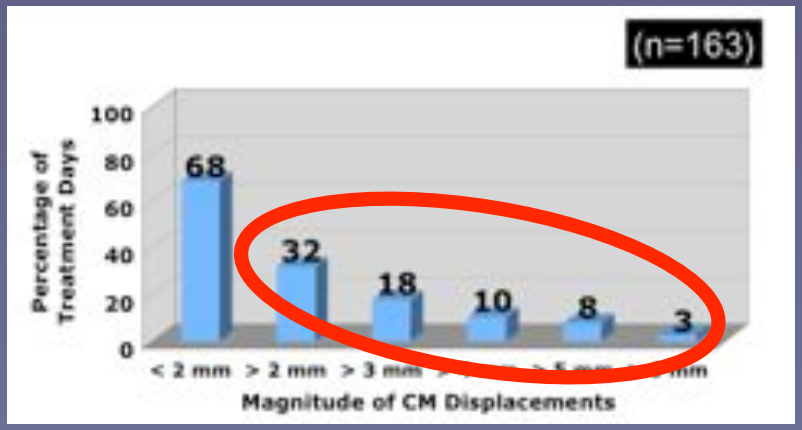
Measuring Prostate Motion





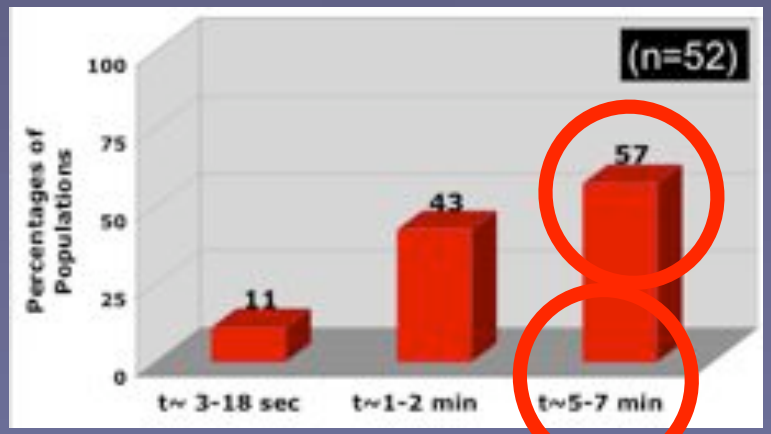
Intra-Fractional Prostate Motion Study

Between Setup and Dose Delivery



32% > 2 mm
10% > 4 mm

All Displacements
> 2 mm

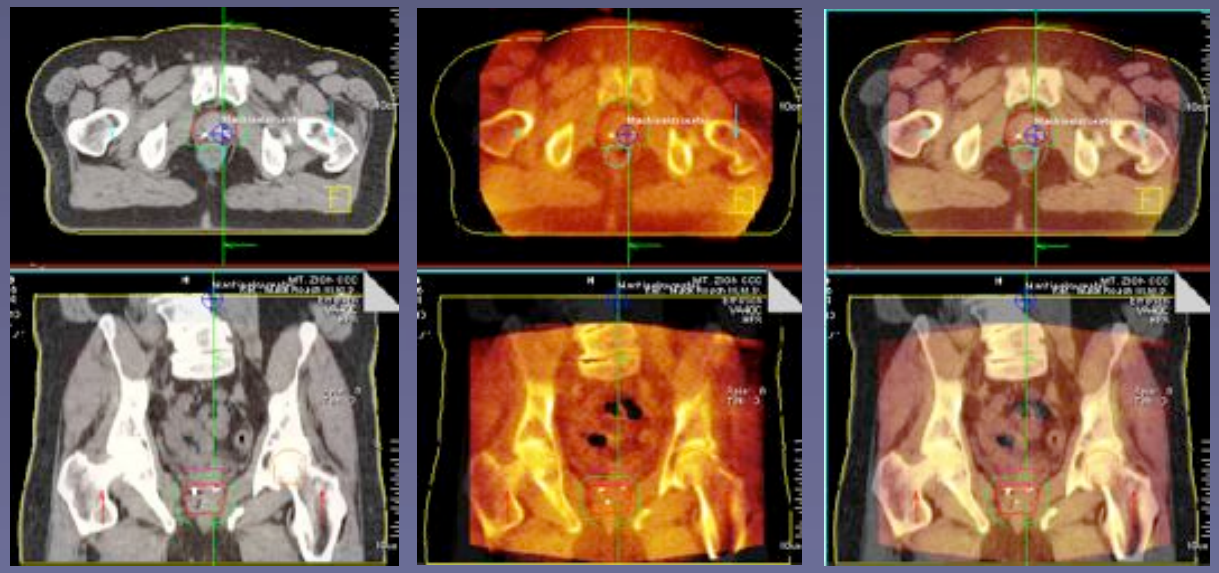


Intra-Fractional Prostate Motion Study

- Prostate is stable during short time periods (i.e. radiation delivery)
- Prostate motion more likely during longer time periods (i.e. between setup and radiation delivery)
- Motion appears to be due mostly to gas in the colon/rectum
- Respiration has little effect on organ motion

Prostate Alignment with MV CBCT

Reference CT | MV CBCT | 50% Blend CT-MV CBCT



As fast, objective and less dose than EPID+markers,

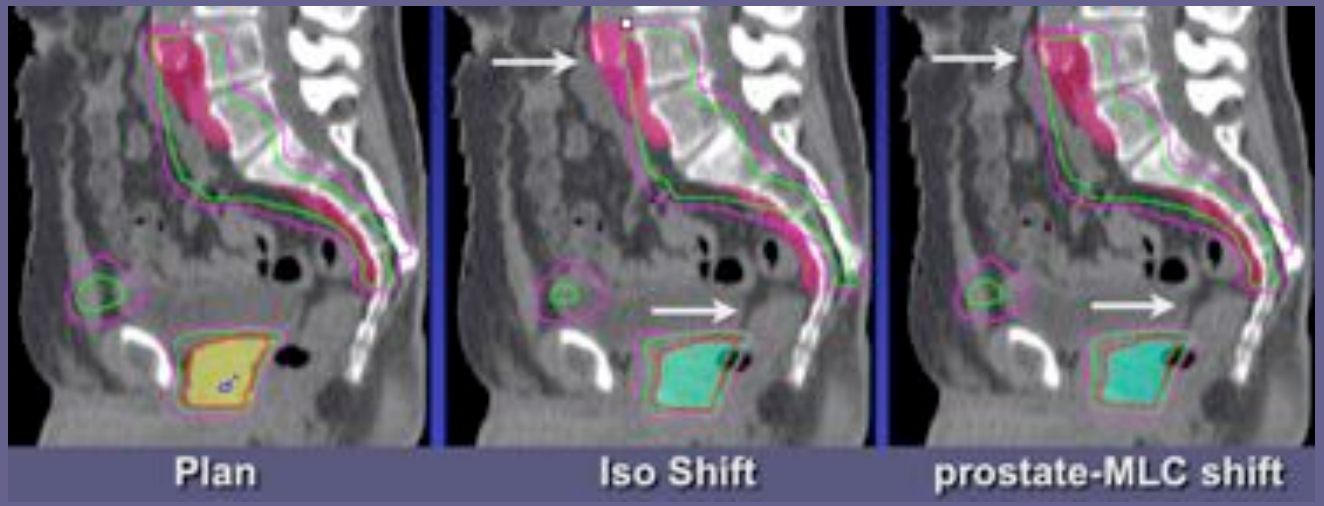
Provides additional information

- **Volumetric info: Rectum, bladder, etc.**
- **Prostate contours -> Dose recalculation**

Daily Prostate Alignment with MVCBCT

ADAPTIVE STRATEGY
for Pelvic Nodal Irradiation in the Treatment of Prostate Cancer

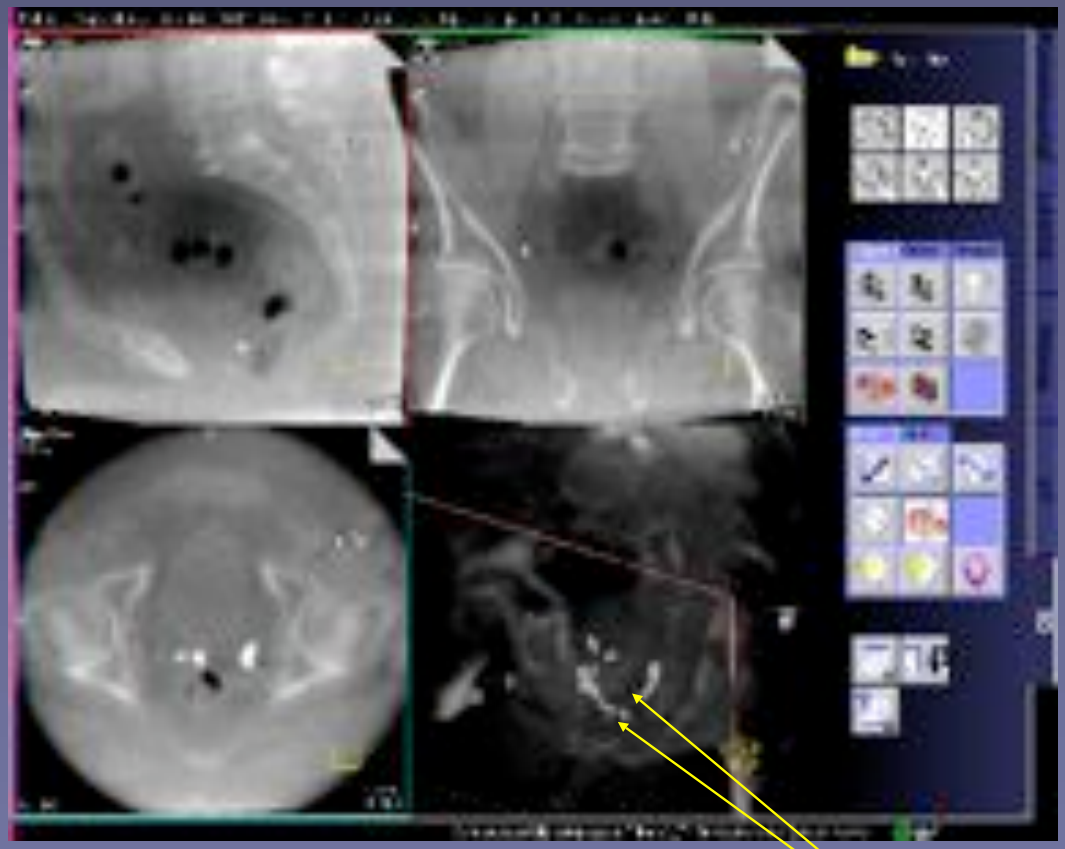
Problems in concurrent IMRT treatment of prostate with pelvic lymph nodes: Independent movements of prostate vs nodes



Courtesy of Ping Xia, UCSF 2007

Patient Setup: Prostate Bed

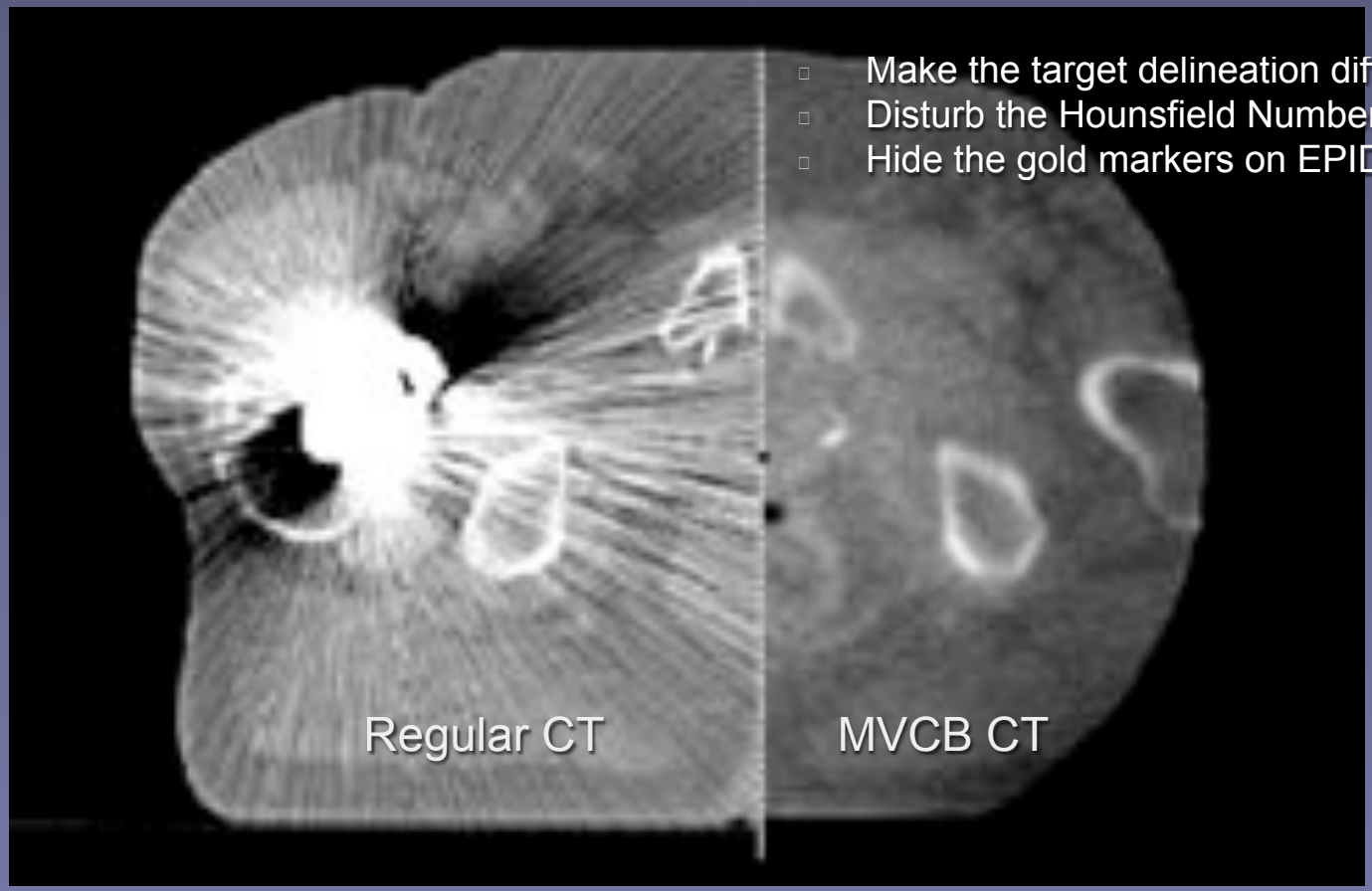
Irradiation of postprostatectomy patient



Markers are distinguished from surgical clips for daily alignment

Hip Prosthesis

Complementing CT with MVCBCT for planning purpose



- Make the target delineation difficult
- Disturb the Hounsfield Number
- Hide the gold markers on EPID

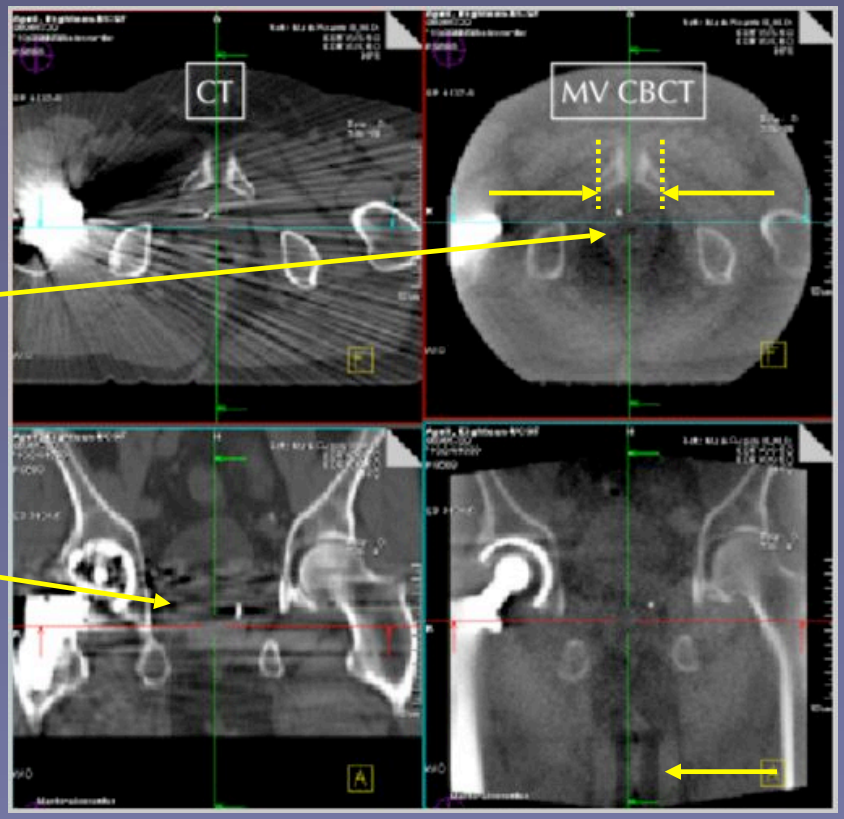
Organ Segmentation with Hip Prosthesis

"In 2005, in Europe and U.S., more than 500,000 hip joints have been replaced."

The US Academy of Orthopedic Surgeon

The MV CBCT images are particularly useful to help delineating:

- The anterior rectum wall.
- The lateral extension of the prostate in the median plane.
- The bladder neck



The prostate volume contoured with the help of MV CBCT was often smaller than what could be guessed from the regular CT in presence of artifacts, preventing overdosage of the rectum.

HDR Brachytherapy for Prostate patient with Bilateral Hip Prostheses

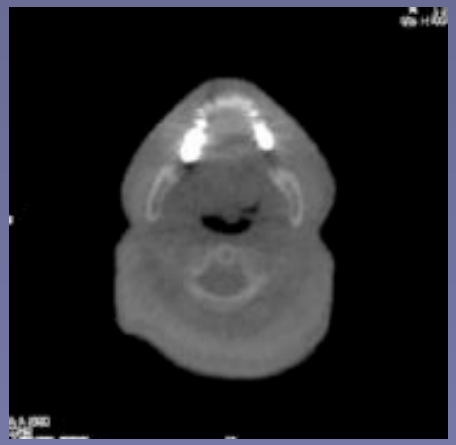
M. Descovich, ABS-2006,
MVCBCT procedure for HDR Brachytherapy

H&N Patient with Dental Implants

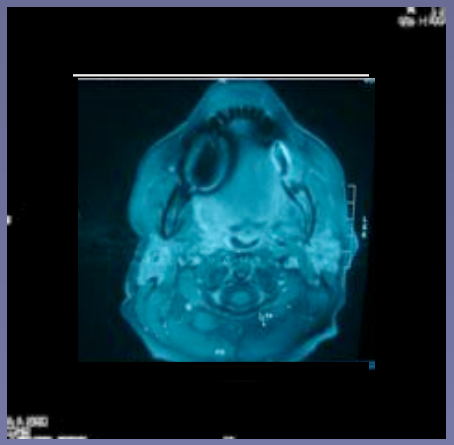
X-ray film

KVCT

MVCBCT



MRI



6 M.U. ~ 3 cGy

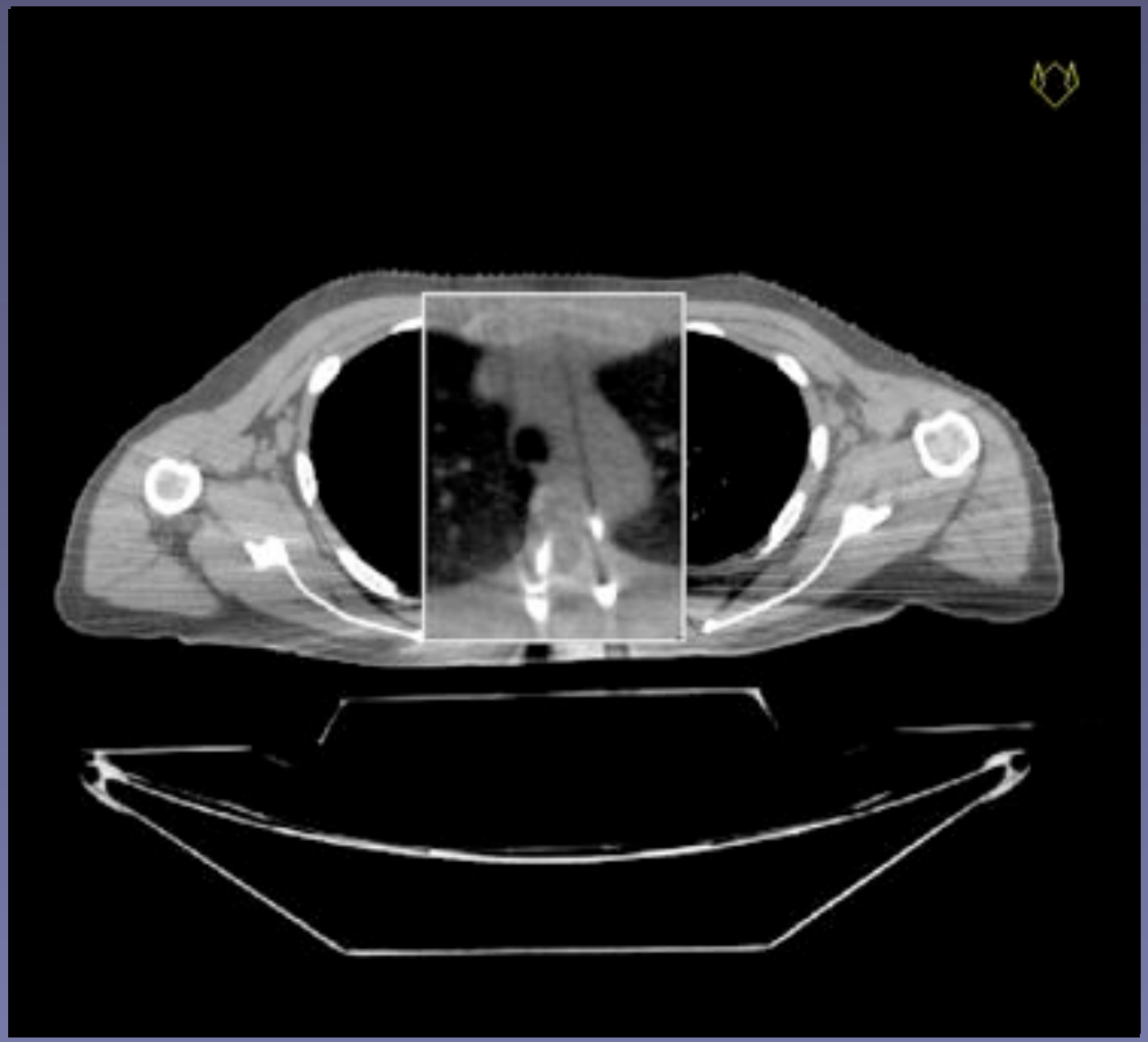
Paraspinous Tumors

Case report

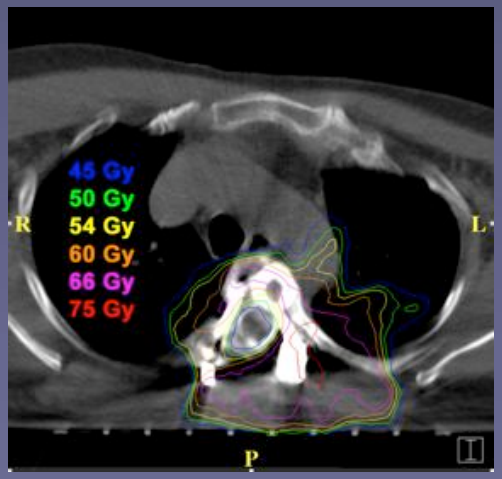
- Surgery + supporting hardware + post-op IMRT
- Spinal cord tolerance limits Dx (palliative)
- Image hardware artifact
  - impairs target delineation
  - hinders treatment verification

- MV CBCT -> Target definition
  -> Daily 3D patient alignment
  -> Improved confidence Px (curative)

Spinal cord delineation with MVCBCT registered to CT for planning purpose, for a patient with a metallic supporting structure



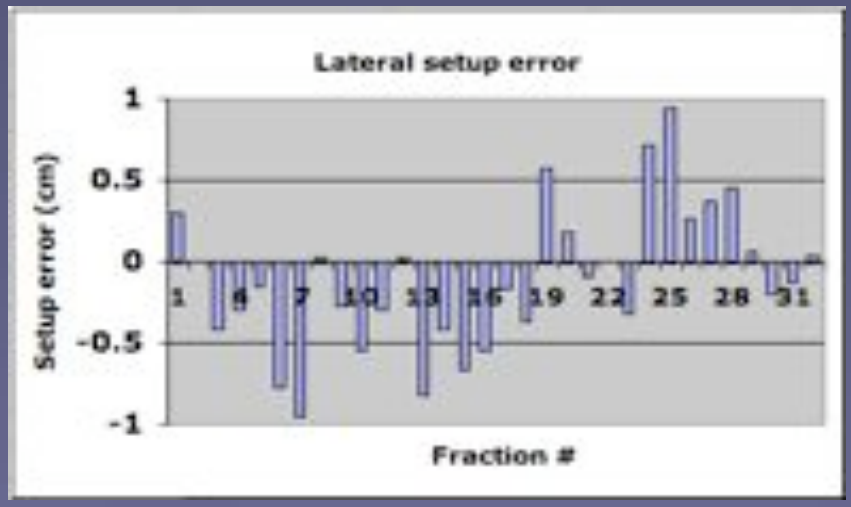
IGRT with MVCBCT of Paraspinous Tumors in the Presence of Orthopedic Hardware

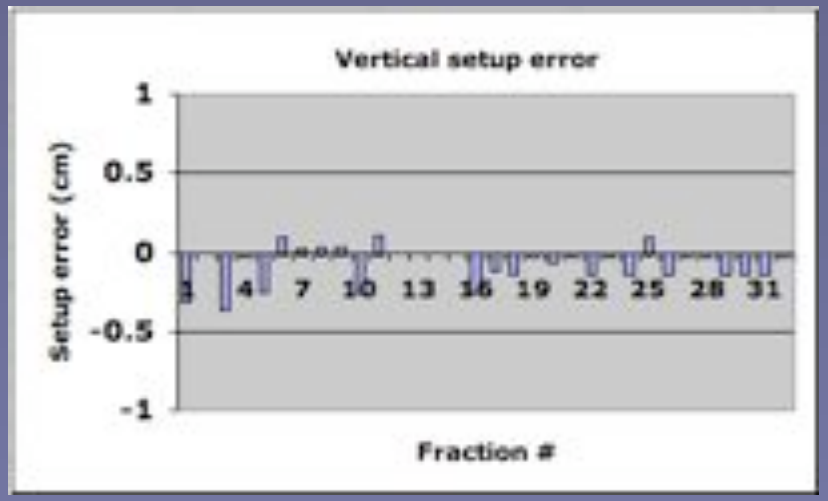


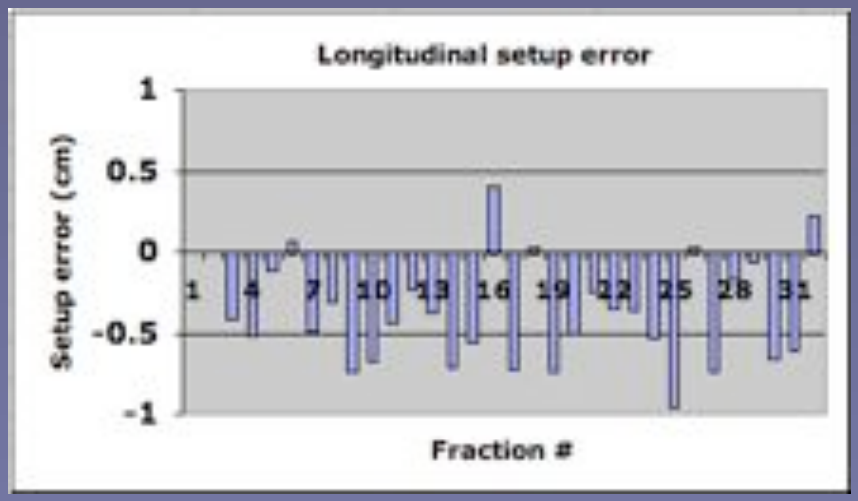
Paraspinous Tumors: Patient Setup

Case Report

Daily Setup Errors (cm)



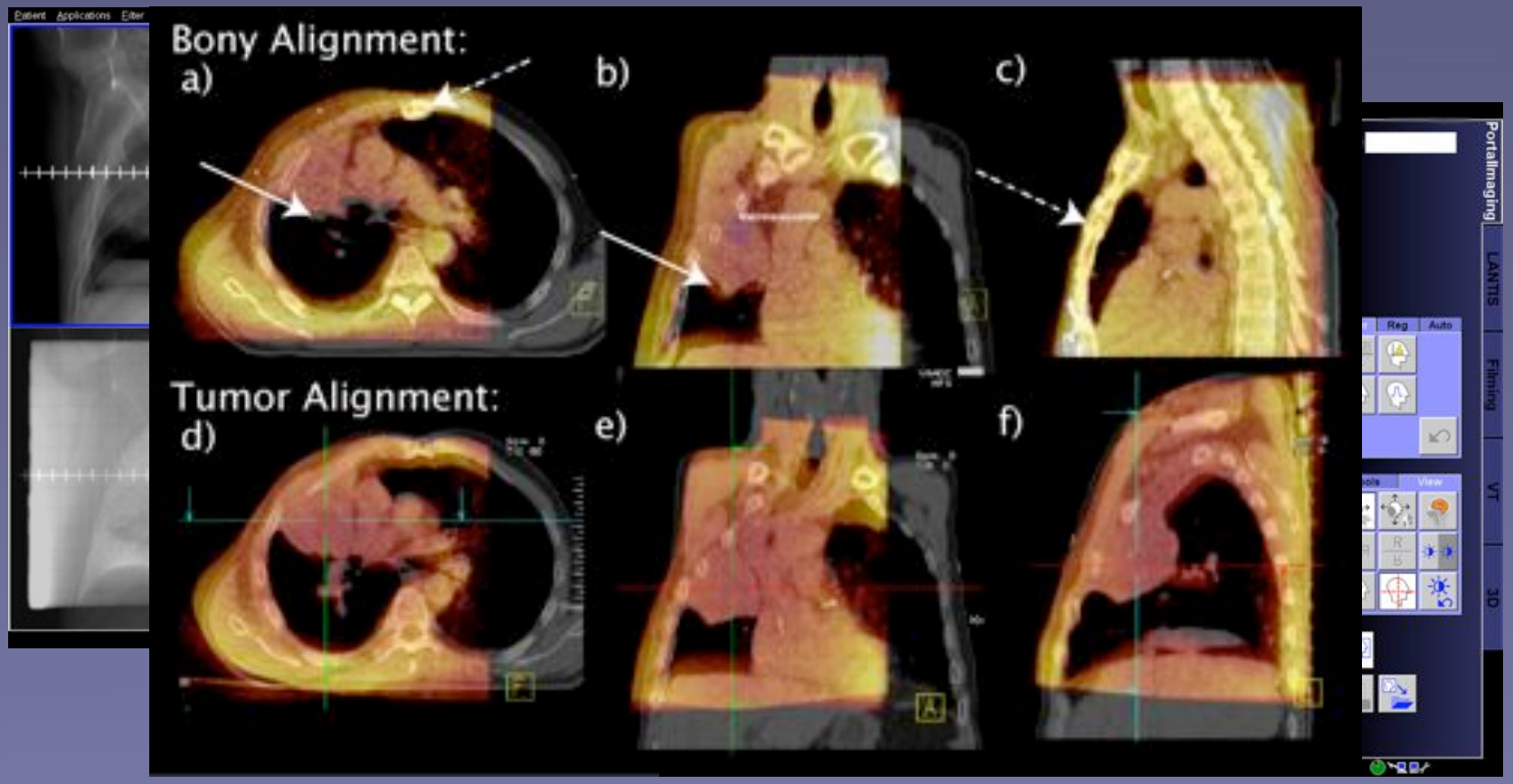




Hansen *et al*., Int. J. Radio. Biol. Phys. 2006, in press

Lung

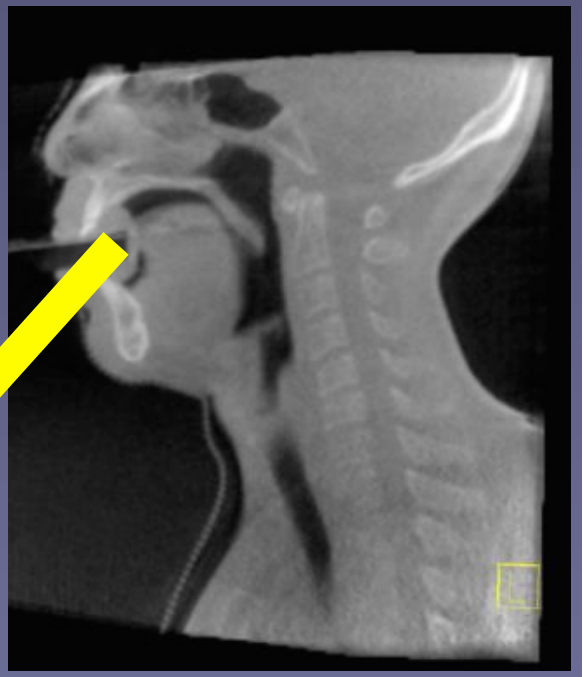
Patient with non-small lung tumor treated with IMRT
Tumor position fairly stable on fluoroscopy
Hypo-fractionated: 8 Gy x 5 fractions



Head and neck patient

Planning CT

Fusion



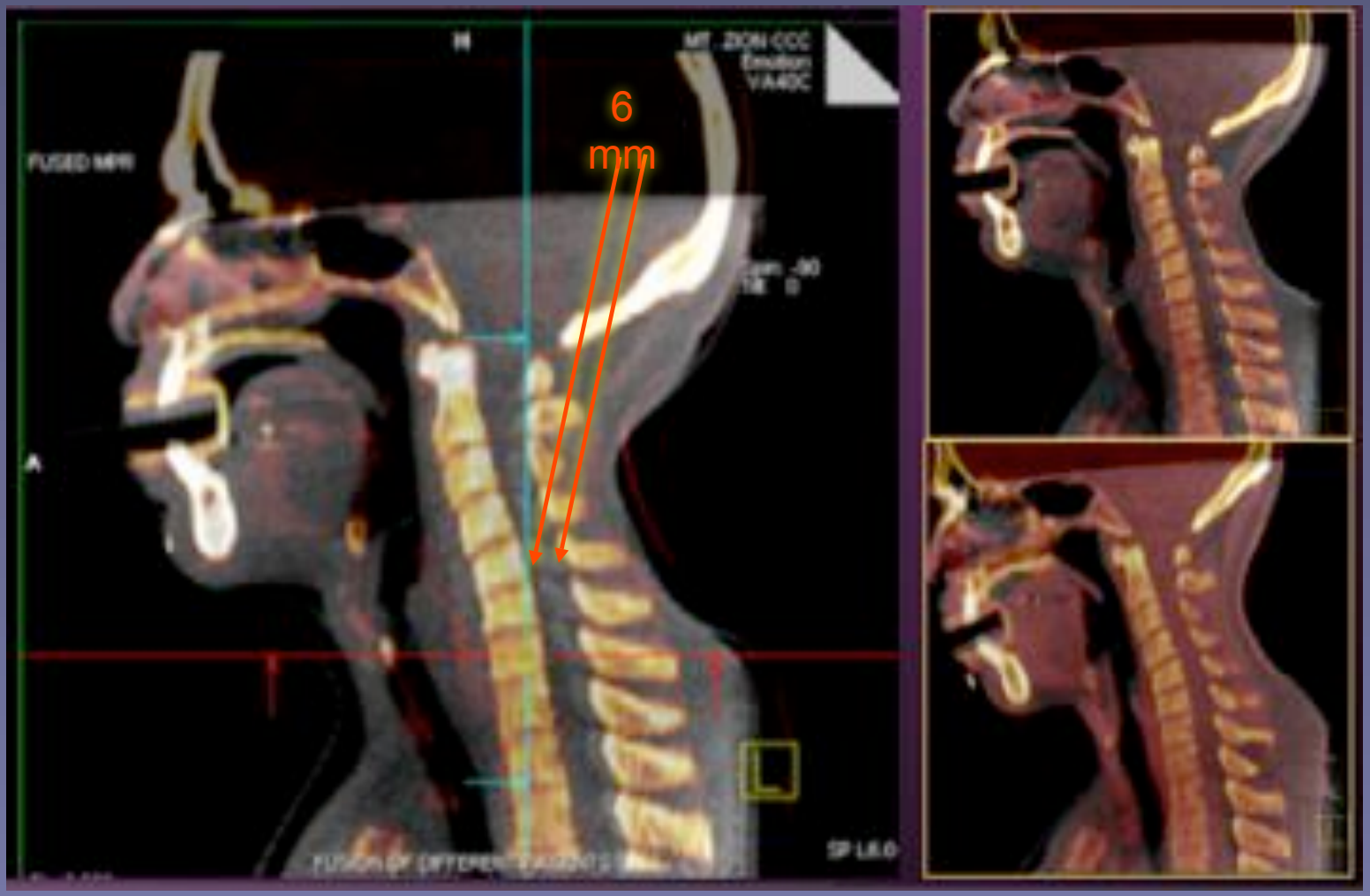
MV CBCT

Positioning: H&N Patients

- 68% of the 2D and 3D isocenter shifts agree within 2mm
- Overall, MV CBCT resulted in more clinical shifts than portal imaging

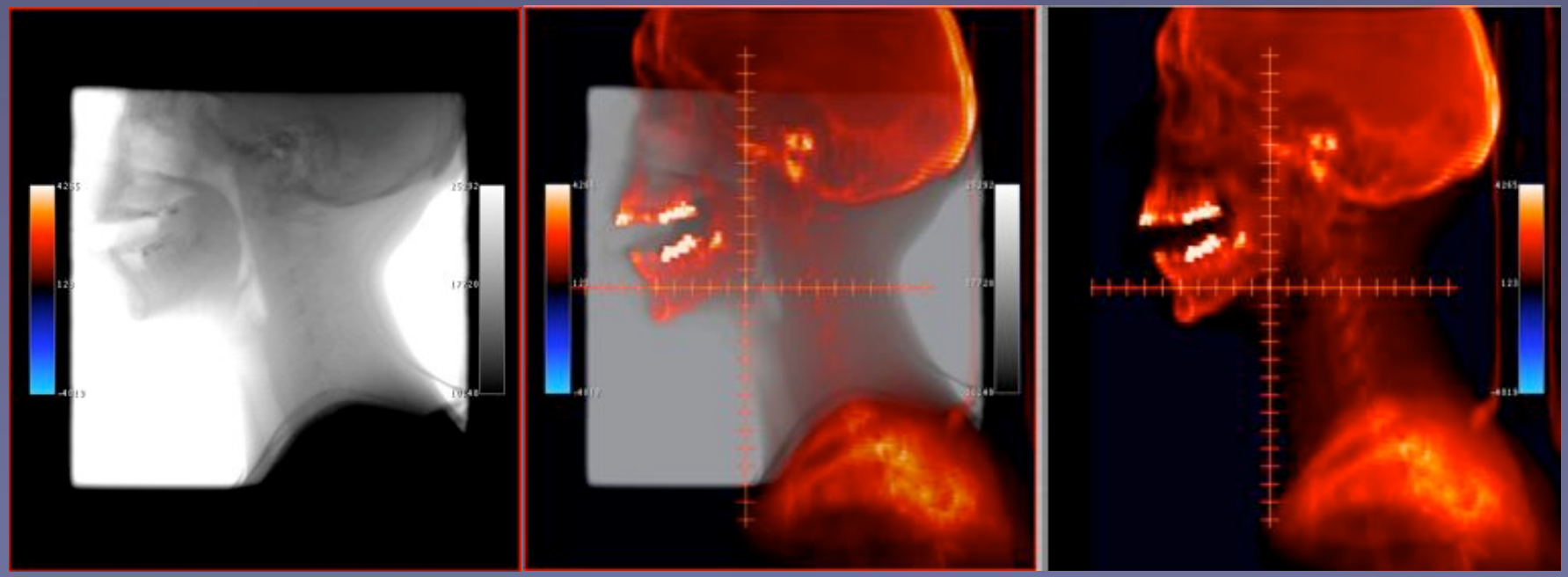
Gillis, A., et al. IJROBP, Volume 63, 1 October 2005, Pages S351-S352

Patient setup: Head & Neck

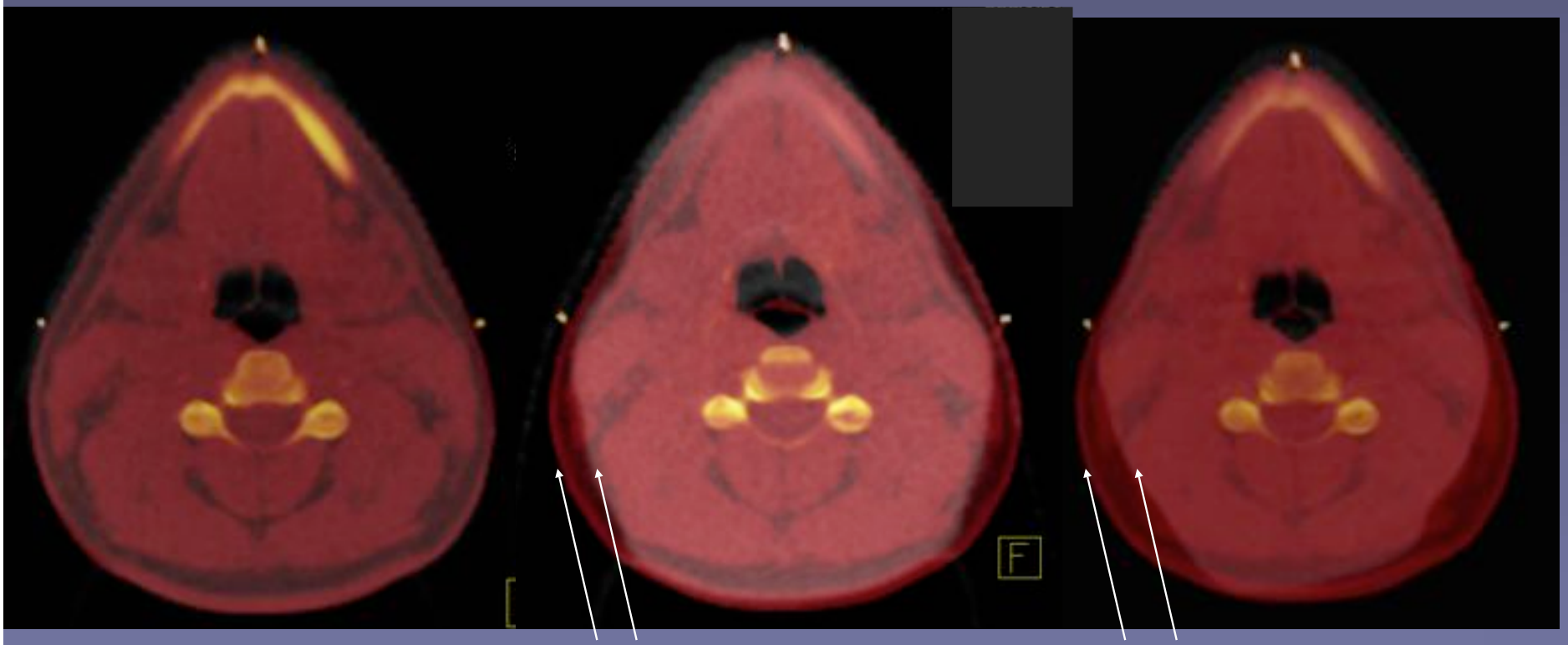


Patient setup with EPID

EPID (1.M.U.) 50%/50% DRR



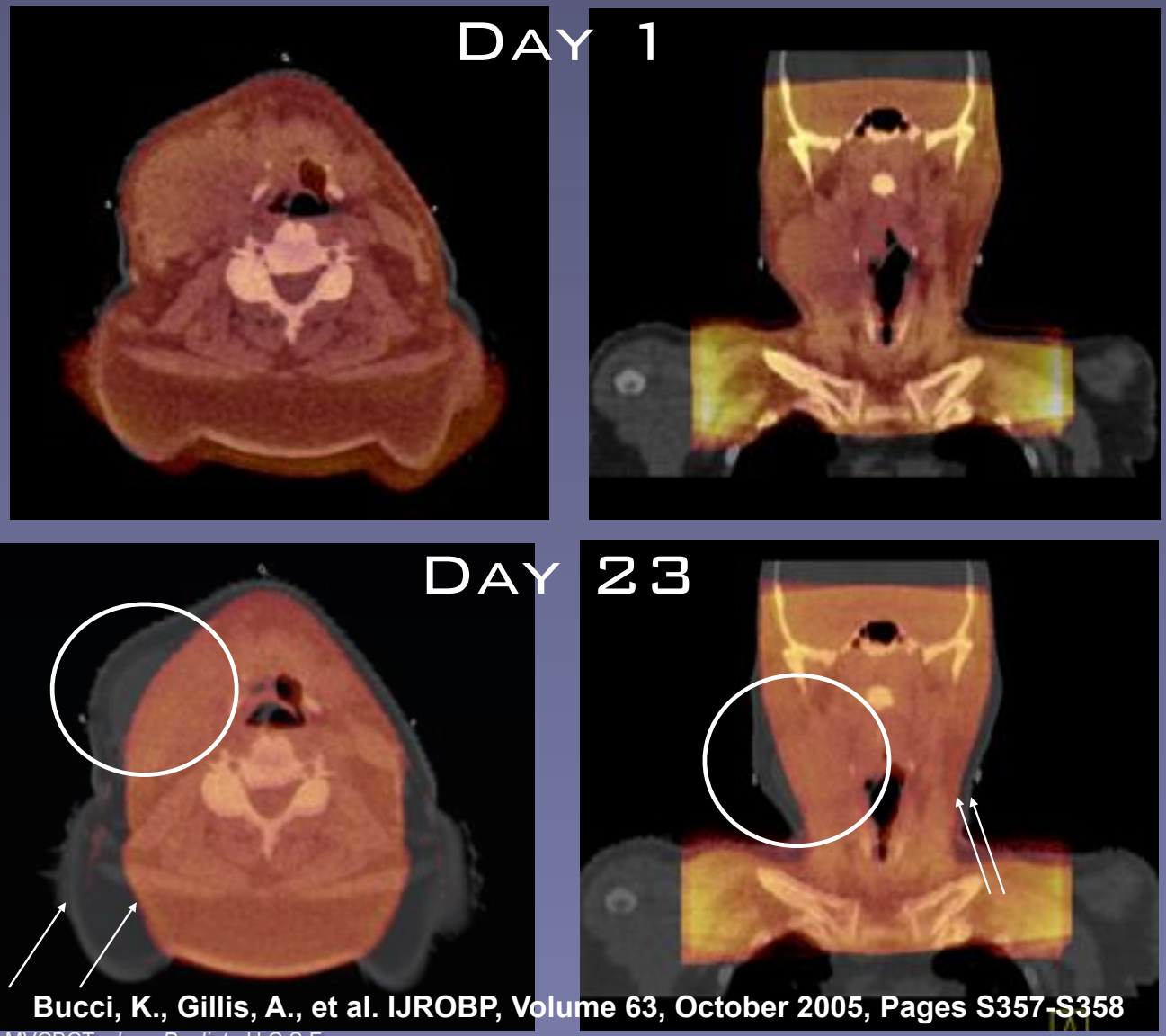
Anatomic Change: Weight Loss



Day 0 Day 24 Day 37

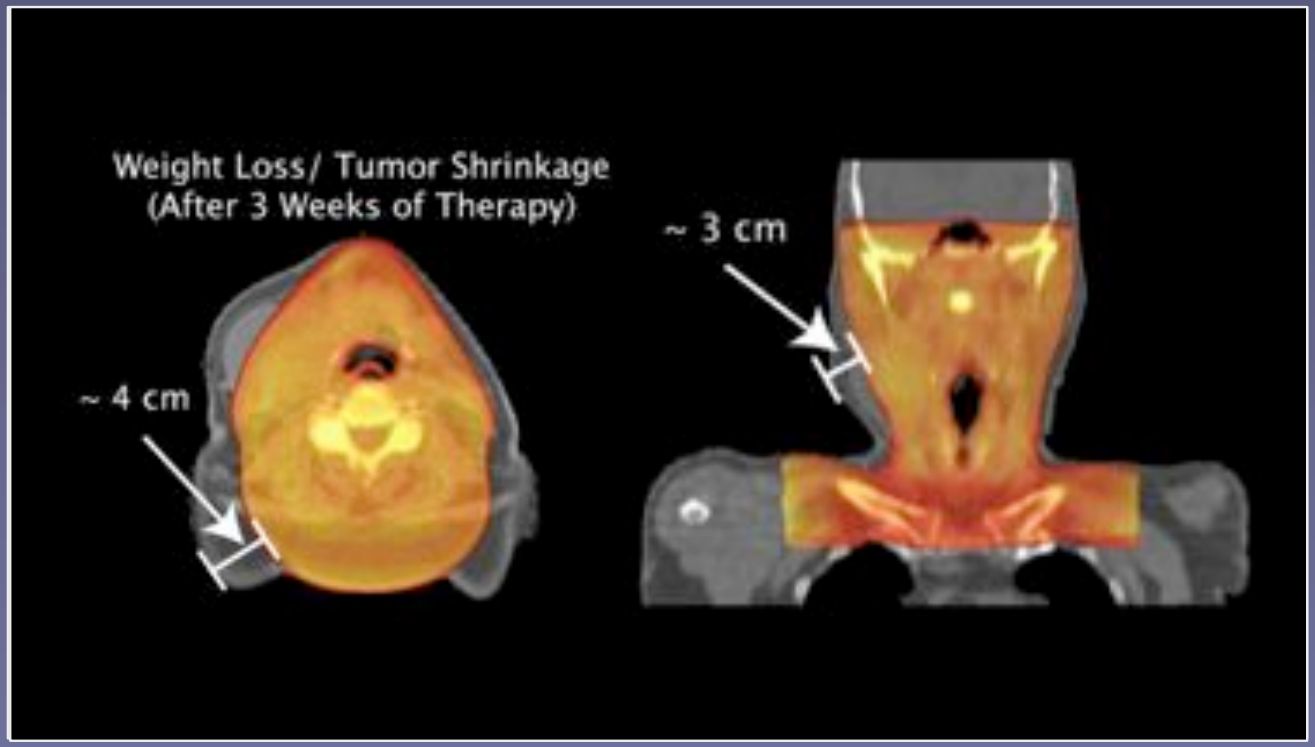
Anatomic Changes

- Weight Loss
- Tumor shrinkage



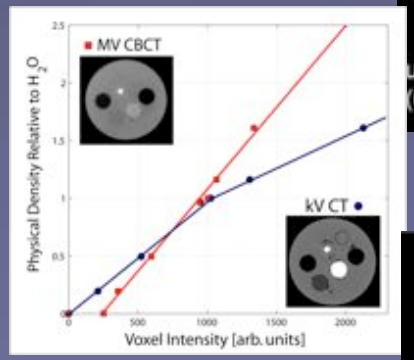
Bucci, K., Gillis, A., et al. IJROBP, Volume 63, October 2005, Pages S357-S358

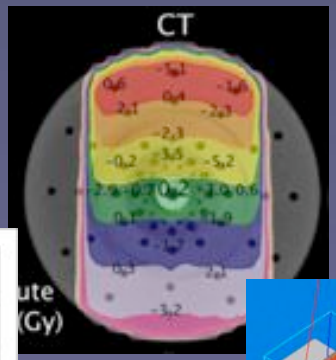
Monitor Anatomical Changes

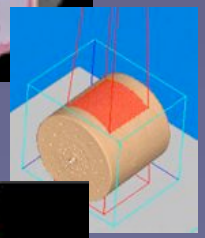


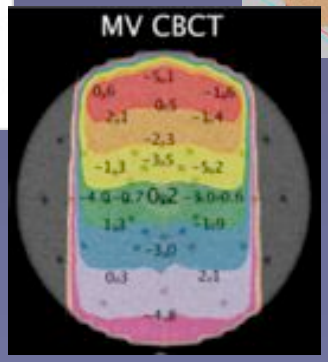
Is the initial plan still valid?
When to replan?
What is the dosimetrical impact?

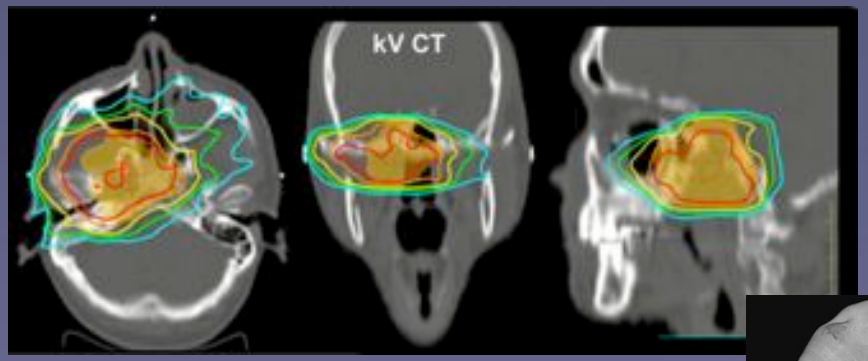
Dose Calculation with MVCBCT

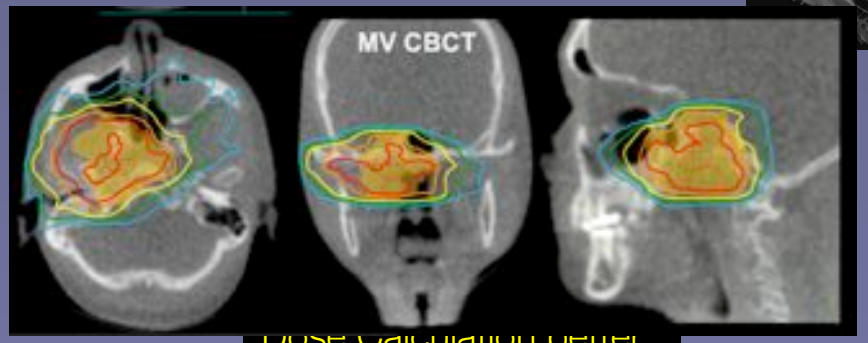








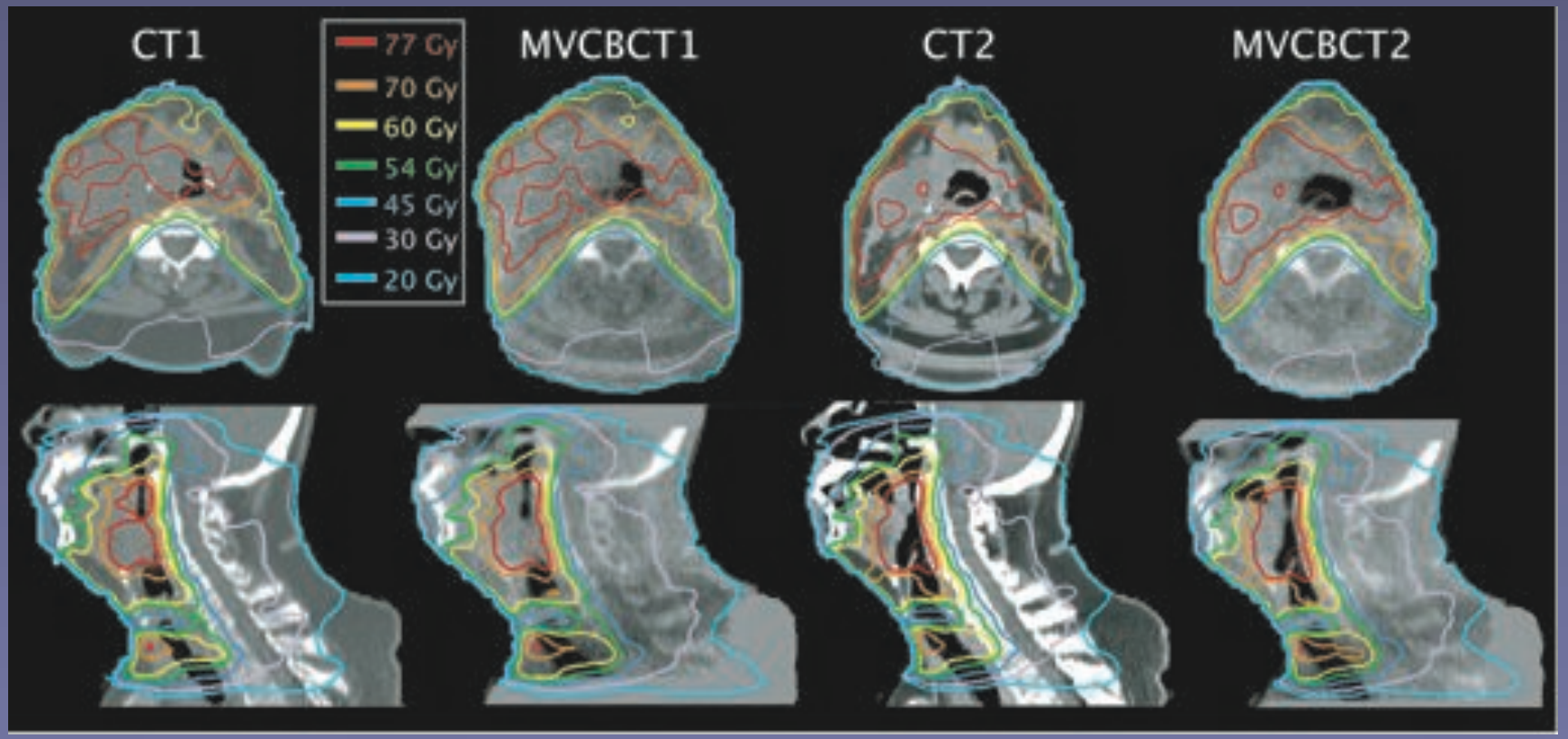




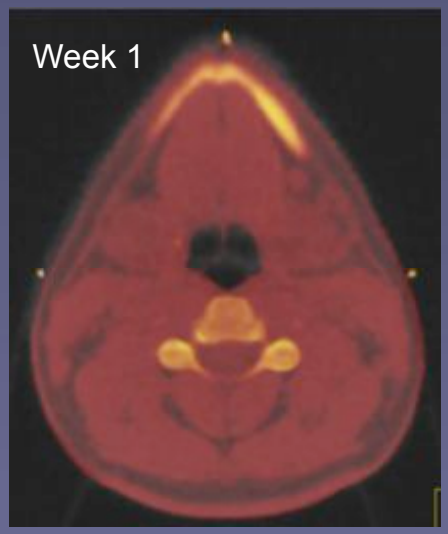
Dose Calculation better
than 3% and 3 mm

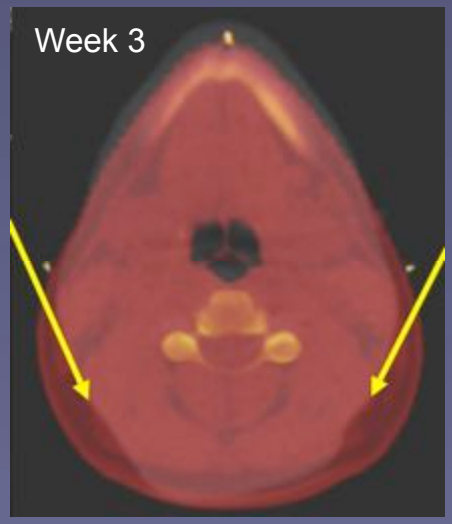
Morin et al., **Dose Calculation using Megavoltage Cone-Beam CT**,
Int. J. Radiation Oncology Biol. Phys. 67(4),1202-1210; 2007.

Comparing dose distributions



Dosimetrical Impact of Weight Loss

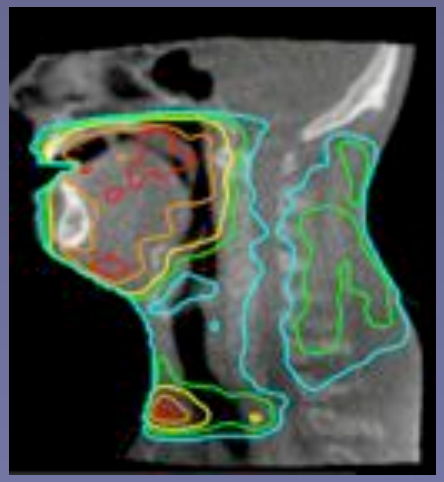


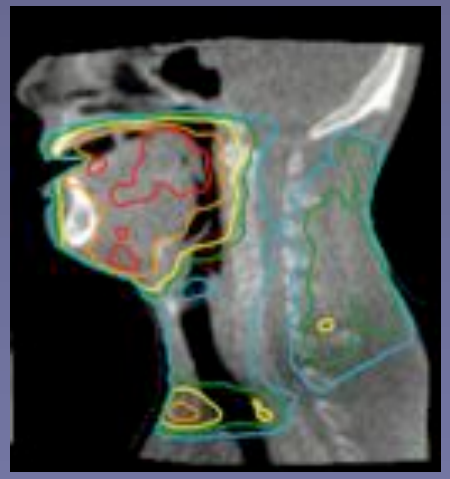


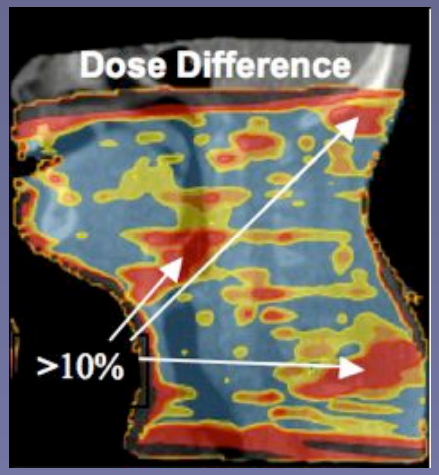
Differences in dose distribution due to anatomical changes

Δ(%) >5%

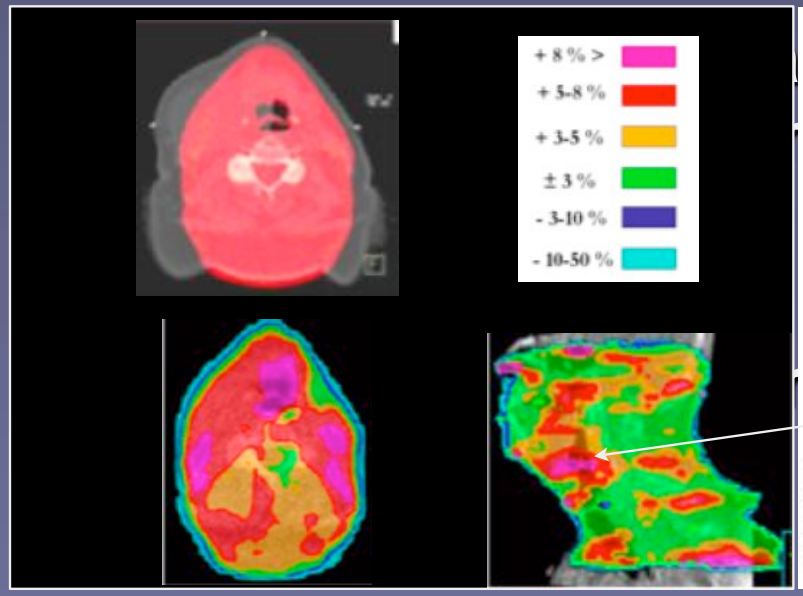
>10%

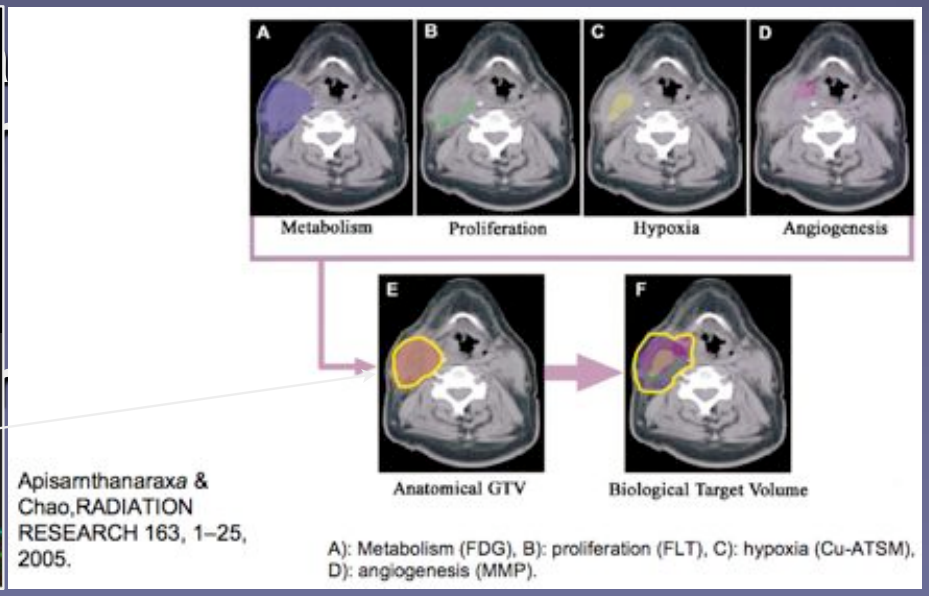






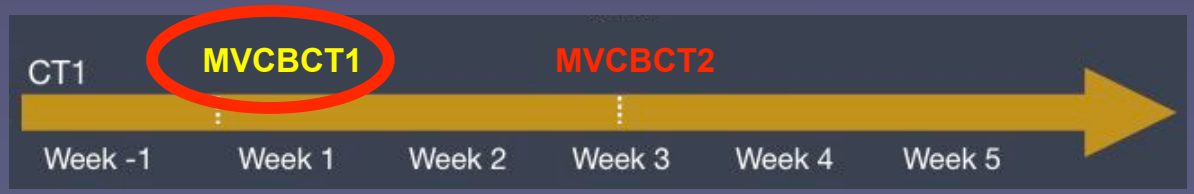
Availability of the Dose Distribution "of the Day"

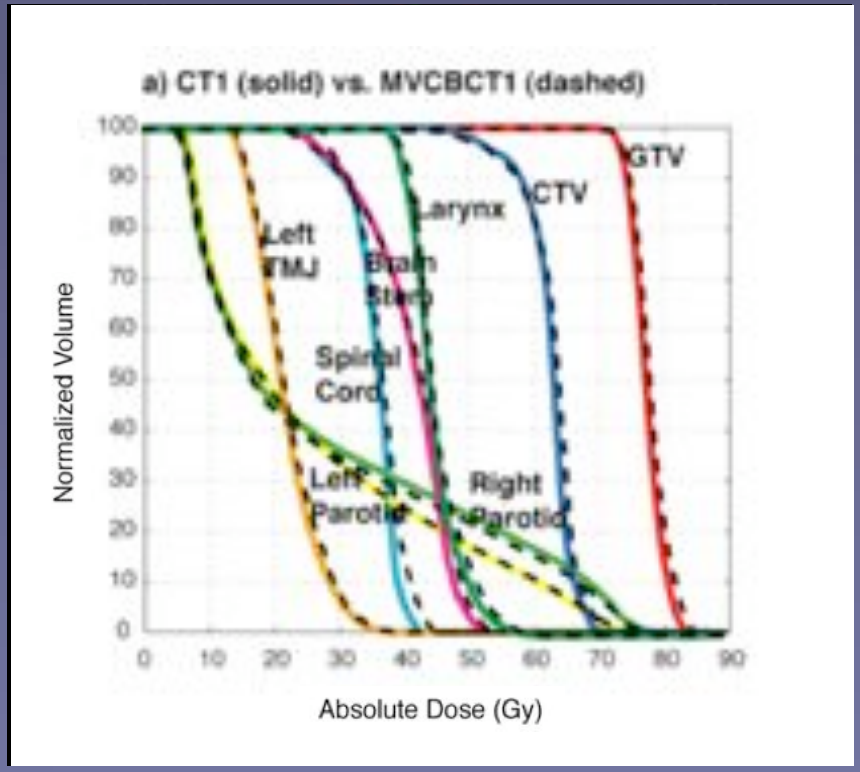




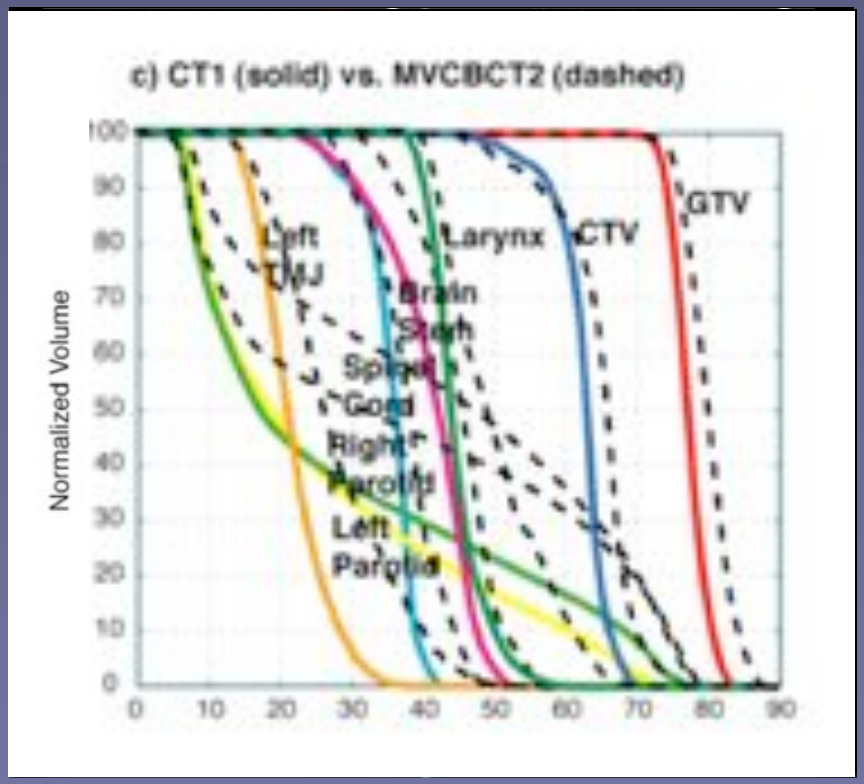
- Enables Dose-Guided Radiation Therapy: **DGRT is an extension of ART** where **dosimetric considerations** constitute the basis of treatment modification and validation.

- Description of MVCBCT
  - Fan Beam vs Cone Beam
  - Basic Principles and Characteristics
  - Image Samples
- Workflow of IGRT with MVCBCT
  - Acquisition, Reconstruction & Registration
  - Absolute Positioning & Alignment Presicion
- Clinical Applications
  - Patient positioning
  - Monitoring of anatomical changes
  - Target delineation with CT non-compatible objects
  - Tomosynthesis, Brachytherapy, etc.
  - Dose calculation to assess dosimetrical impact
- **Dose-Guided Radiation Therapy**


CT1
MVCBCT1
MVCBCT2
Week -1
Week 1
Week 2
Week 3
Week 4
Week 5


a) CT1 (solid) vs. MVCBCT1 (dashed)
Normalized Volume
Absolute Dose (Gy)
GTV
CTV
Larynx
Left TMJ
Spinal Cord
Left Parotid
Right Parotid
0
10
20
30
40
50
60
70
80
90
100

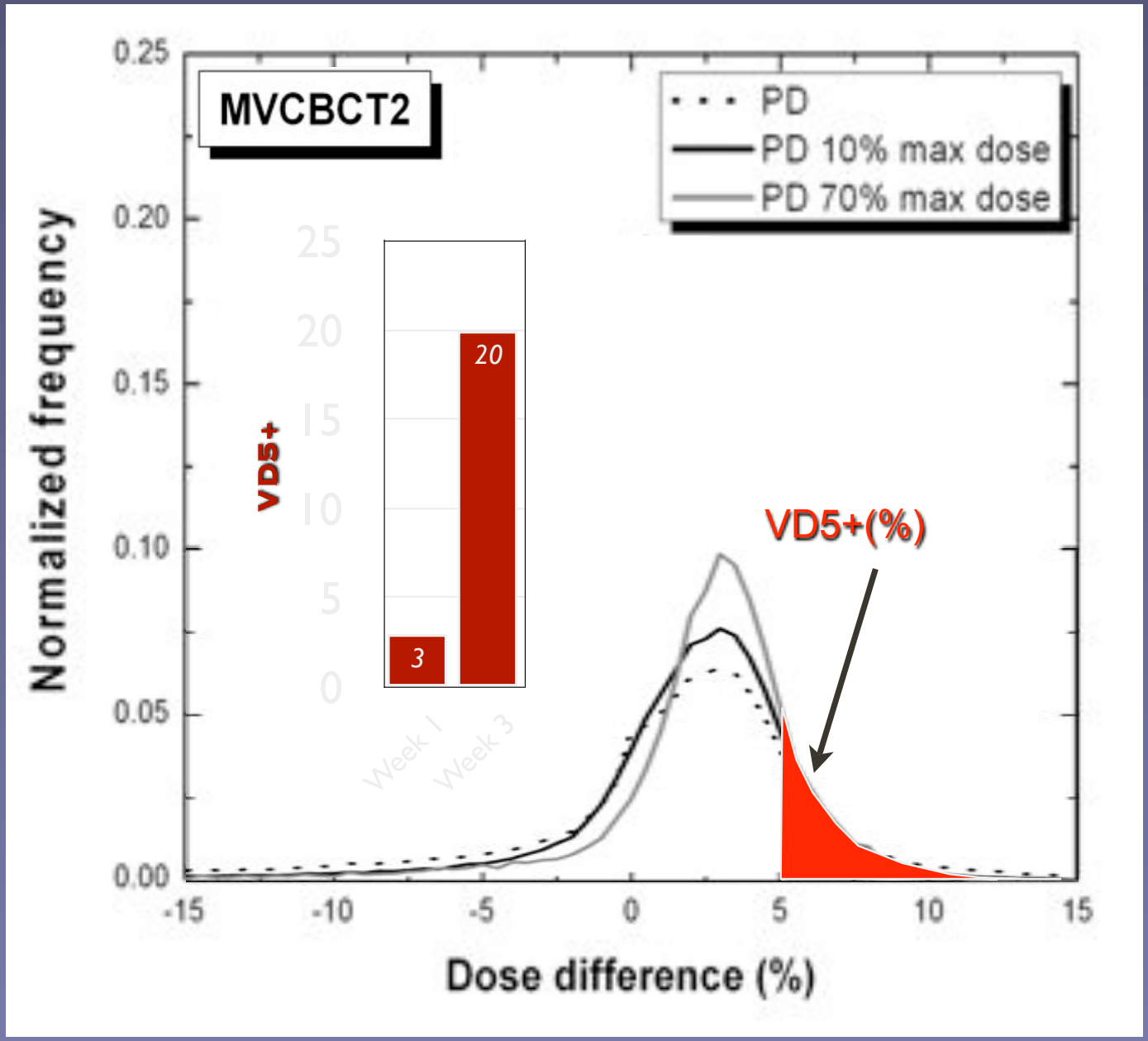
Dose Comparison



Right Parotid dose increased from 26 Gy to 42 Gy

Pt#3

Day 24


MVCBCT2
PD
PD 10% max dose
PD 70% max dose
Normalized frequency
0.25
0.20
0.15
0.10
0.05
0.00
-15
-10
-5
0
5
10
15
Dose difference (%)
VD5+
25
20
15
10
5
0
20
3
Week 1
Week 3
VD5+(%)

MV CBCT: Summary

- MVision is a reliable, fast and efficient IGRT tool
  -> Has been used >3000 times on patients

- Provide 3D anatomy of patient in treatment position
  -> Patient Setup
  -> Monitoring of anatomical changes
  -> Tumor evolution

- Accurate electron density for dose calculation
  -> Assess dosimetric Impact
  -> Planning in presence of high-Z material

- Allows dose re-calculation for DGRT

Main Collaborators

UCSF

- Michelle Aubin
- Jean-Francois Aubry
- Josephine Chen
- Hong Chen
- Cynthia Chuang
- Martina Descovich
- Bruce Faddegon
- Amy Gillis
- Alex Gottschalk
- Olivier Morin
- Mack Roach III
- Joycelyn Speight
- Lynn Verhey
- Ping Xia
- and several others...

Siemens

- Ali Bani-Hashemi
- Fahard Ghelmansarai
- Paco Hernandez
- Dimitre Histrov
- Bijumon Gangadharan
- Matthias Mitschke

This work is supported by Siemens O.C.S.

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- Pouliot J., Aubin M., Aubry J.F., et. al. **Megavoltage cone-beam CT: Récents développements et applications cliniques pour l'IMRT**, Cancer et Radiothérapie, France, 10, 258-268 ; 2006.
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- Chen J, Morin O, Aubin M, et al. **Dose-Guided Radiation Therapy using Megavoltage Cone-Beam CT.** Br J Radiol 2006;79:S87-S98.
- Pouliot J, Bani-Hashemi A, Chen J, et al. **Low-dose megavoltage cone-beam CT for radiation therapy.** Int J Radiat Oncol Biol Phys 2005;61:552-560.