



University of Michigan  
Medical School

# Imaging for RT

Scott W. Hadley PhD

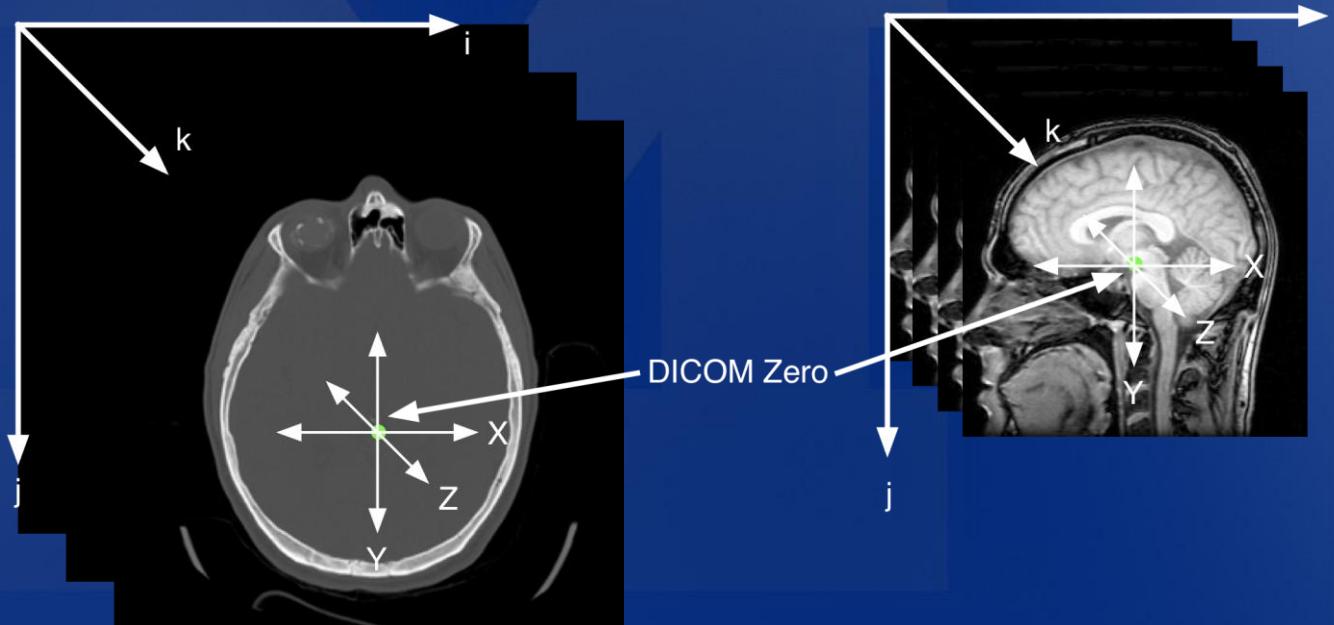
*The* Department of Radiation Oncology  
University of Michigan

# Imaging Used in RT

- CT including 4DCT
- PET and PET-CT
- SPECT
- Ultrasound
  - IGRT and Brachytherapy
- MRI
- Tomography is imaging by sections

# Images and Coordinates

- Tomography – image from cross sections
- Every Image has its own coordinate system
- Anatomy is translated and rotated in the image



# Transformation $T$

- Image Transformation
  - Geometric transformation that relates one image to another
  - Transformation Matrix  $T$

$$\mathbf{v}_{voxel}^{ref} = T \mathbf{v}_{voxel}^{test} = S_{xyz} T_{xyz} R_x R_y R_z \mathbf{v}_{voxel}^{Test}$$


scale      translation      rotations

# Image Registration

- Determination of  $T$ 
  - Manually
  - Similarity Measure (SM)
    - Mutual Information
    - Cross Correlation
  - $T=?$
- Optimization of  $T$  using a SM

# Image Fusion

- Putting it together and showing the result

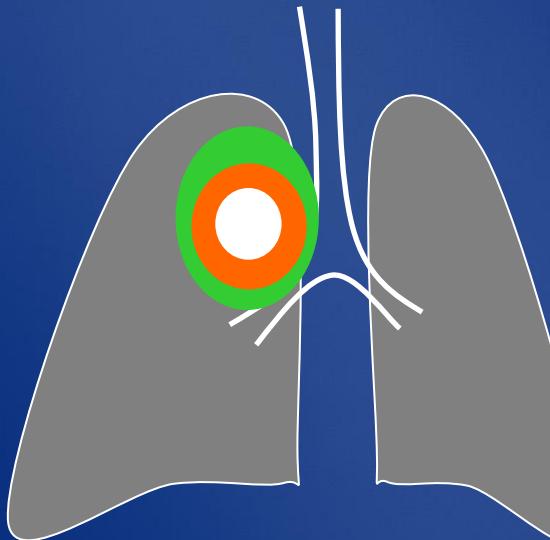


$T$

Fusion

# ICRU Report 50 and 62

- Gross Tumor Volume (GTV)
  - *gross demonstrable extent of growth*
- Clinical Target Volume (CTV)
  - *GTV + subclinical tissue to be treated (e.g. lymph nodes)*
- Planning Target Volume (PTV)
  - *CTV + margin to assure that Rx dose is delivered to CTV*



# Radon Transform & Tomography

- Radon Transform
  - Integral transform (summation from calculus)
  - CT summation of attenuation coefficients
  - PET & SPECT summation of radioactivity
  - It makes the sinogram
- Inverse Radon Transform
  - Makes the 3D tomographic images from the sinogram



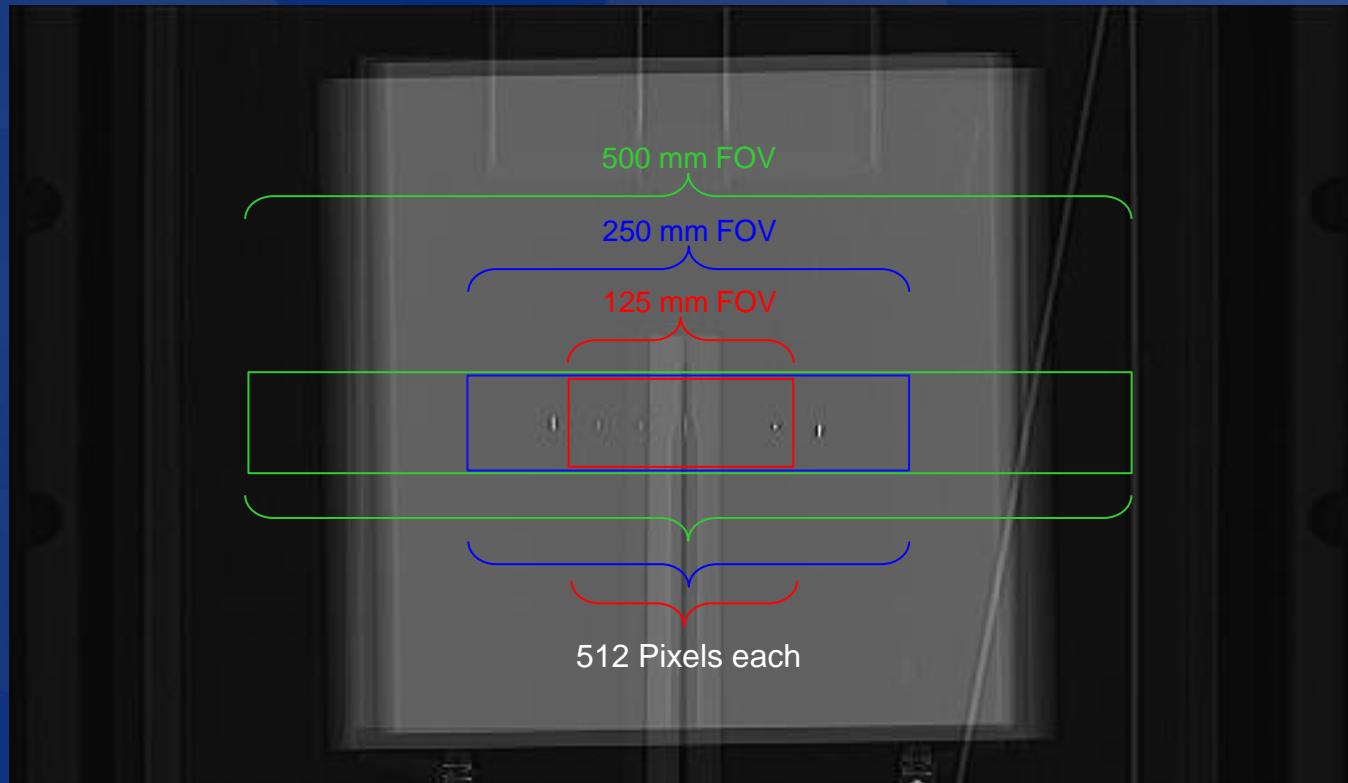
# 3D Imaging Parameters

- Field of View (FOV) & Image Size
  - In plane resolution  $\text{FOV}/(\text{image size})$
  - mm/pixel
- Slice Thickness (mm)
- Slice Spacing (mm)

# Localizer Image

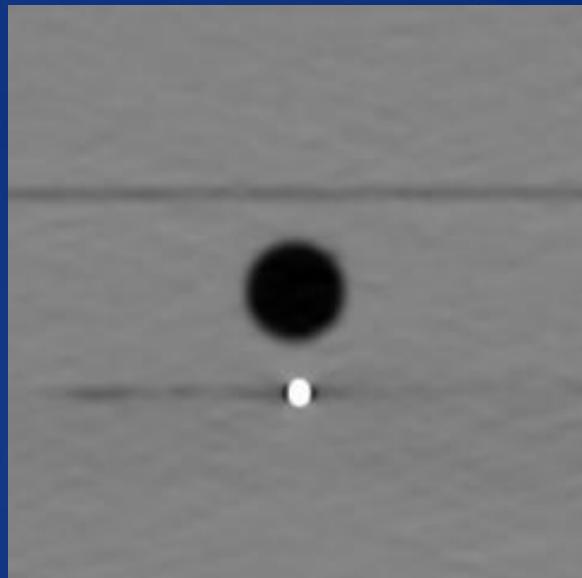
Set

- FOV
- Slice Width/Spacing



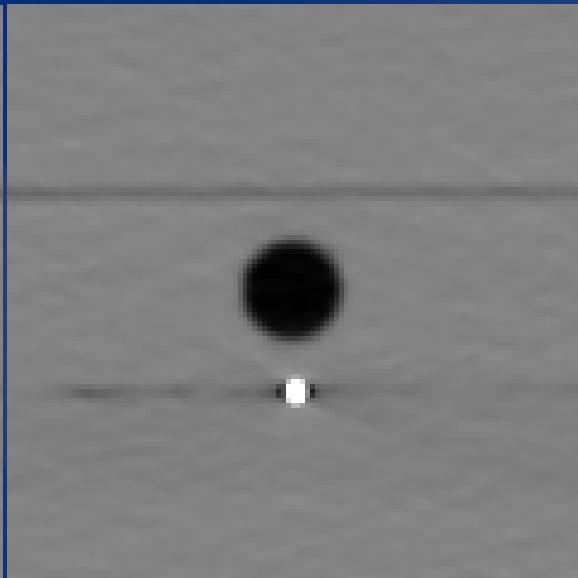
# Impact of FOV

125mm FOV



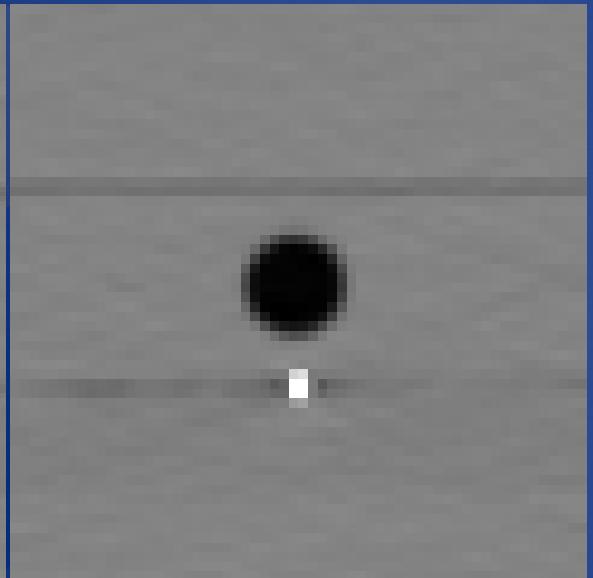
125mm / 512 pixels  
0.24 mm/pixel

250mm FOV



250mm / 512 pixels  
0.49 mm/pixel

500mm FOV



500mm / 512pixels  
0.98 mm/pixel

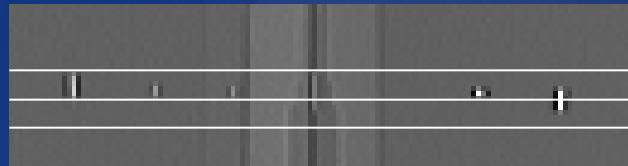


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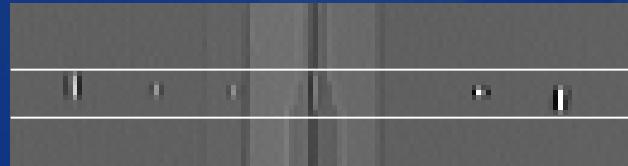
# Slice Spacing/Thickness



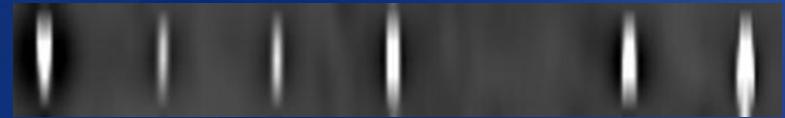
} 1mm



} 3mm



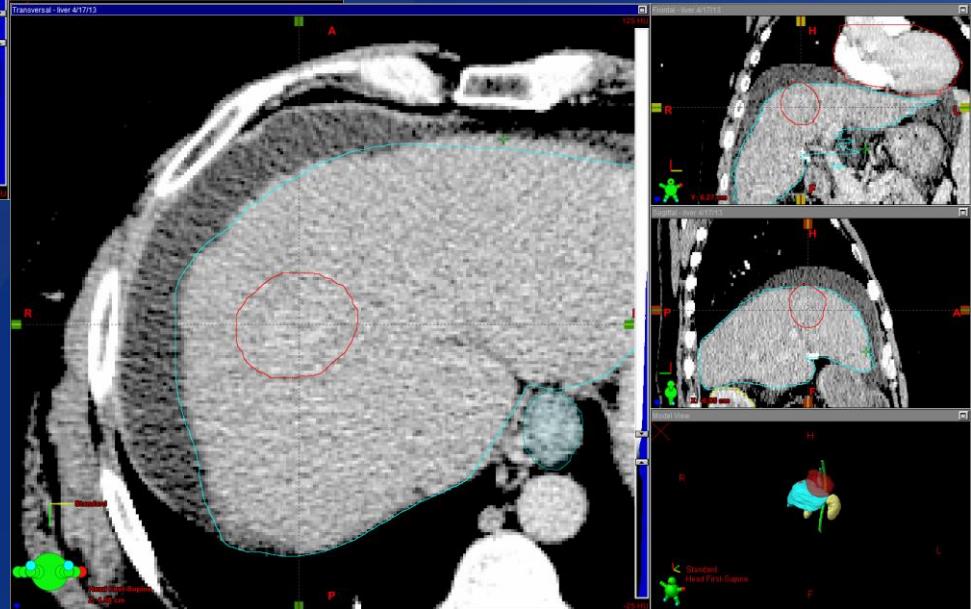
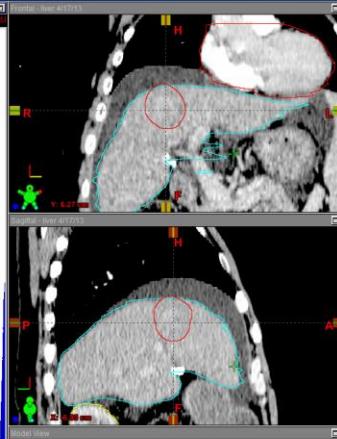
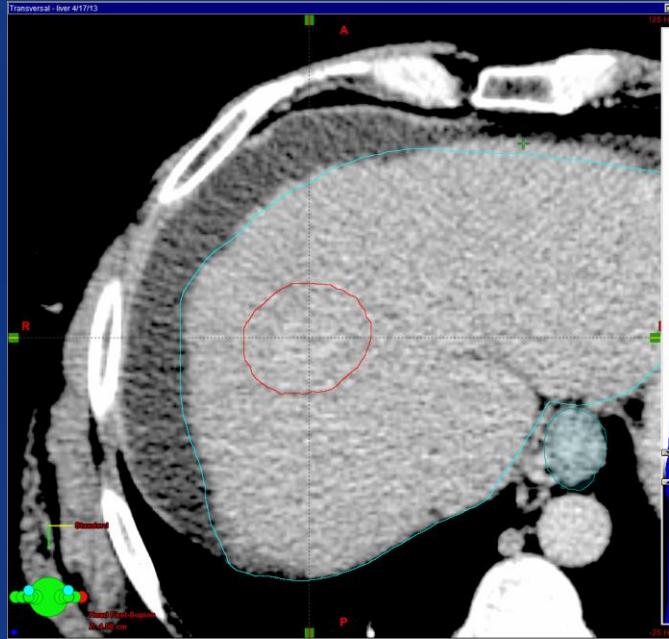
} 5mm





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# Interpolation off/on



# Attenuation and HUs

- Hounsfield Unit (HU)
  - Rescaling and normalization of attenuation  $\mu$

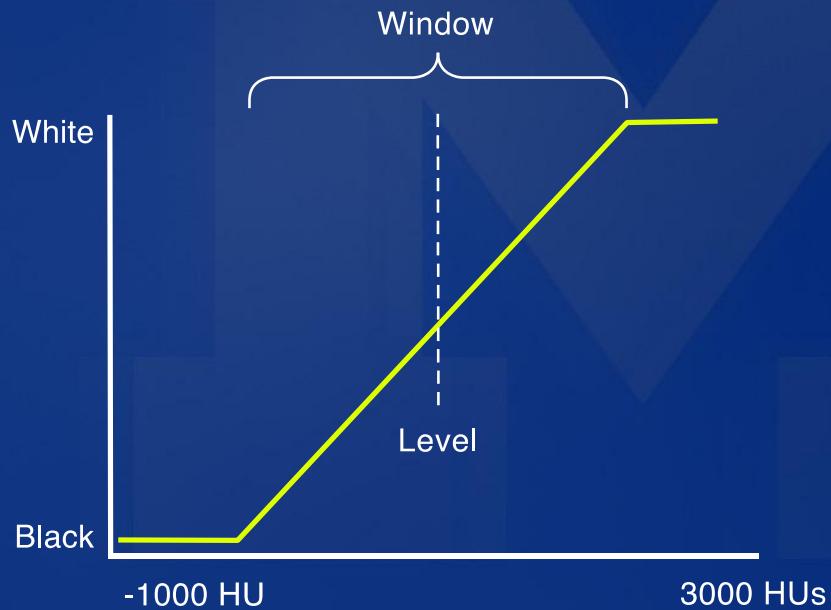
$$HU(x) = \left[ \frac{m(x) - m(H_2O)}{m(H_2O)} \right] * 1000$$

- “x” medium of interest
- Converts  $\mu$  into more useful range for digital representation
- 12 bit DICOM representation
  - $2^{12} = 4096$  gray levels

Medium	HUs
Air	-1000
Lung	~-700
Soft Tissue	-300 to -100
Water	0
Blood	30 to 45
Bone	$\geq 700$
Aluminum	2300

# Window and Level for Display

- Maps HUs to display gray scale
  - HUs range from -1000 to +3500 (and more)
  - Displays range from black to white (or another color)



	<b>Window</b>	<b>Level</b>
Abd	350	40
Bone	1500	300
Lung	1400	-500
Liver	150	50

# Window Level Example



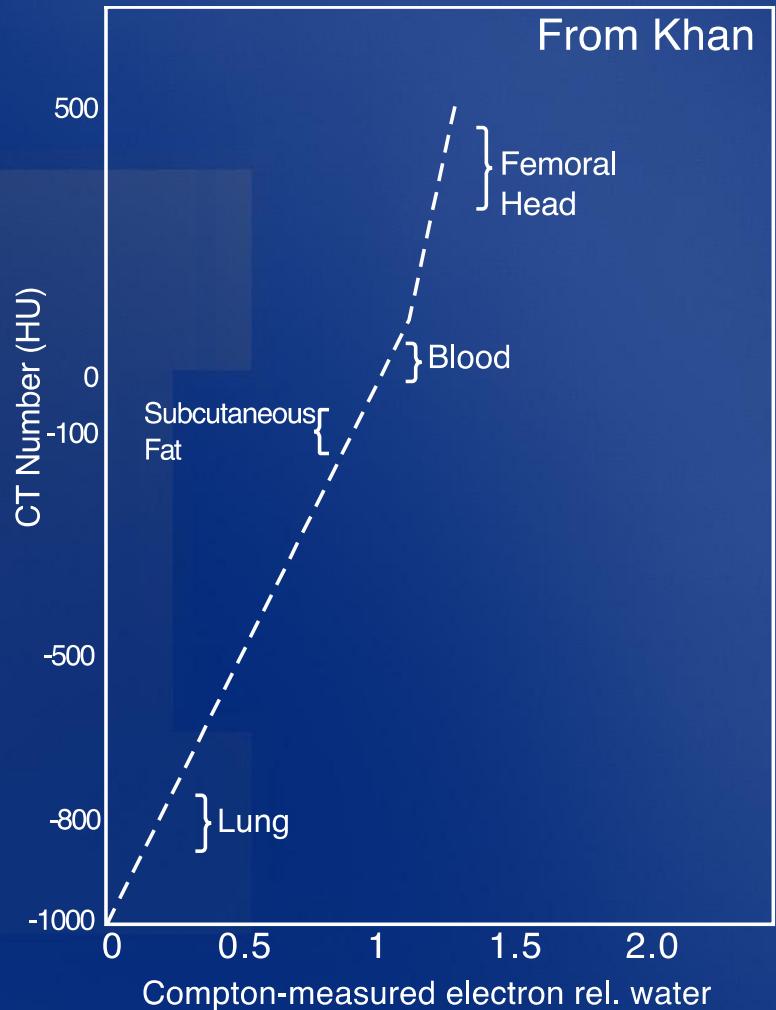
Lung  
W 1400  
L -500

Liver  
W 150  
L 50

Abd  
W 350  
L 40

# CT to Density

- Needed for dose calculation
  - Density corrections
- MV X-Rays = Compton
- Compton is  $e^-$  density dominated
- Lookup table us used to convert for dose calculation

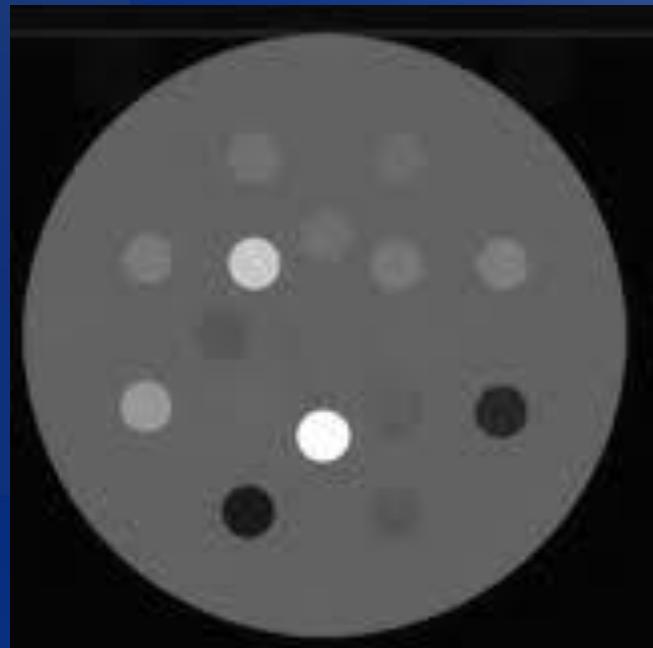


# Tissue Characterization Phantom

- $e^-$  density relative to water
- Part of CT scanner & TPS commissioning



[gammex.com](http://gammex.com)



# CT Scanner Lexicon

- Rosetta stone of CT terminology
  - Transcribes similar CT technology with different marketing names

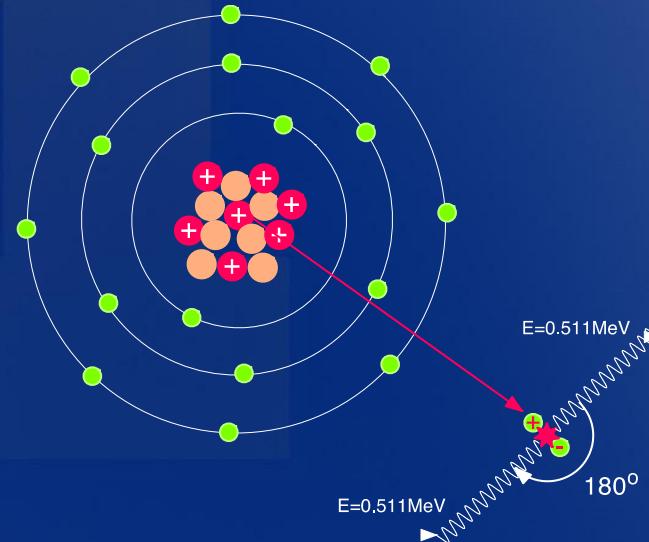
<http://www.aapm.org/pubs/CTProtocols/documents/CTTerminologyLexicon.pdf>

1. Scan acquisition and user interface basics				
Generic description	GE	PHILIPS	SIEMENS	TOSHIBA
The portion of the <b>user interface</b> where scans are prescribed	Exam Rx	Scan Procedure	Examination	eXam Plan
Other portions of the <b>user interface</b> , such as where reconstructed images are viewed	Desktop	Active viewer	Various "task cards", such as "Viewing"	Active display
<b>CT localizer radiograph</b> (i.e. the scanned projection radiograph, often acquired by the CT system to allow the user to prescribe the start and end locations of the scan range)	Scout	Surview	Topogram	Scanogram
<b>Axial scan mode:</b> Data acquisition while the patient table remains stationary; the table position may be incremented between scans	Axial	Axial	Sequence	Scan & View, Scan & Scan, Volume, Wide Volume

# Positron Emission Tomography PET Imaging

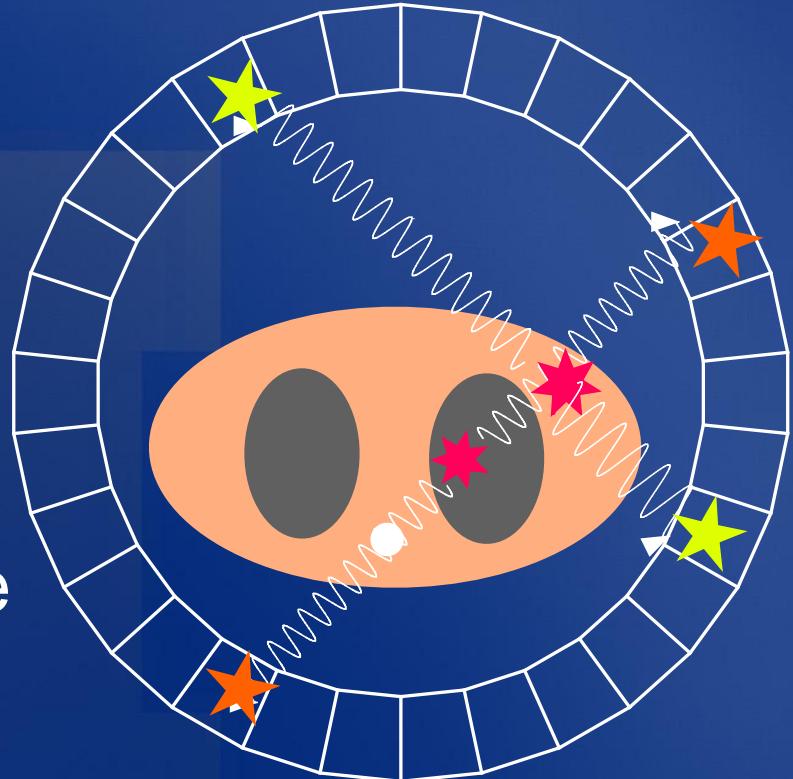
- Tomographic imaging using radioactive decay that results in positron  $e^+$
- Isotopes that undergo beta decay

Isotope	Half-life
Carbon-11	20.4 m
Nitrogen-13	10 m
Oxygen-13	2 m
Fluorine-18	110 m



# PET

- NaI crystals to detect 511keV X-rays
  - Multiple rings
- Coincidence Counting
  - Two signals at same time
- Forms the sinogram



# PET-CT Systems

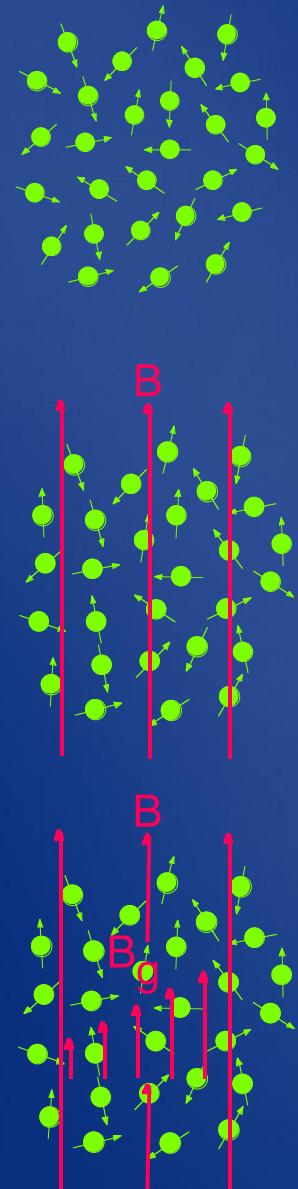
- CT attenuation map for PET correction



# MRI brief explanation

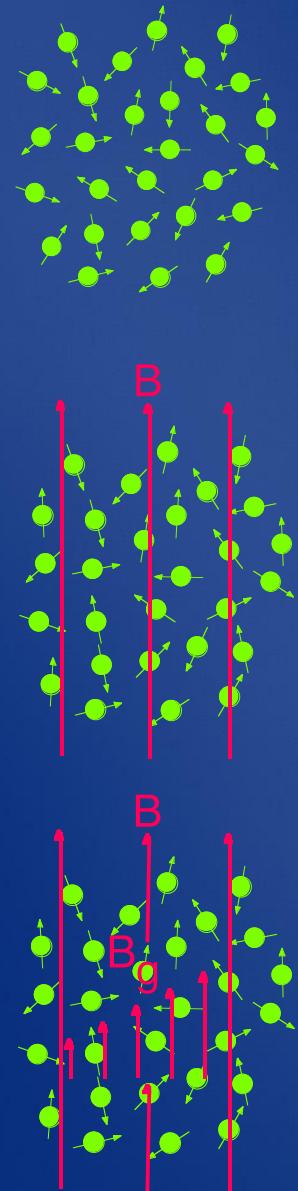
- Tesla strength magnetic field  $B$
- Hydrogen (of  $\text{H}_2\text{O}$ ) resonates
  - Frequency  $\omega$  proportional to  $B_0$
  - $\omega_0 = \gamma B_0 \dots \gamma = 42.6 \text{ MHz/T}$

$B_0(\text{T})$	$f(\text{Mz})$
0.5	21.3
1.5	63.9
3.0	127.8
5	213



# MRI brief explanation

- RF pulses to excite spins
  - TR time between excitation pulses
  - TE time between echoes
- Excitation Pulse
  - FID free induction decay
- Spins relax after excitations
  - T1 is longitudinal relaxation time
  - T2 is the lateral relaxation time



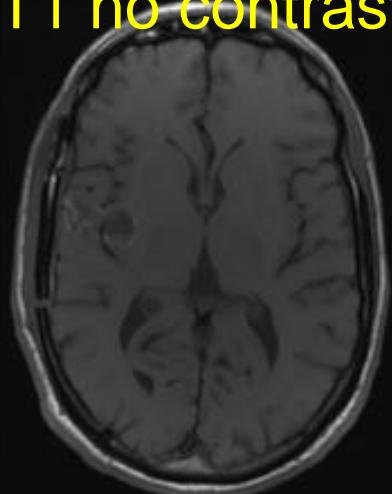
# T1, T2 and Flair

	T1	T2	Flair
Tumor	Dark	Bright	Bright
Cyst	Dark	Bright	Dark
Fat	Dark	Dark	Bright

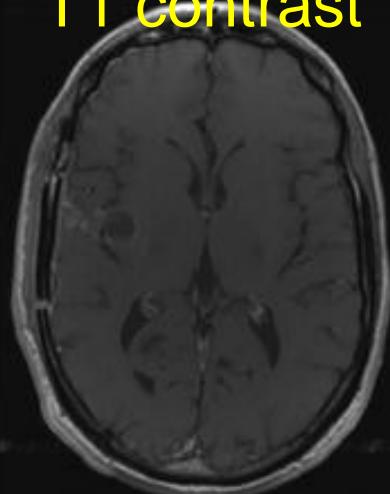
Adapted from <http://spinwarp.ucsd.edu/NeuroWeb/Text/br-100.htm>

# MRI Imaging modes

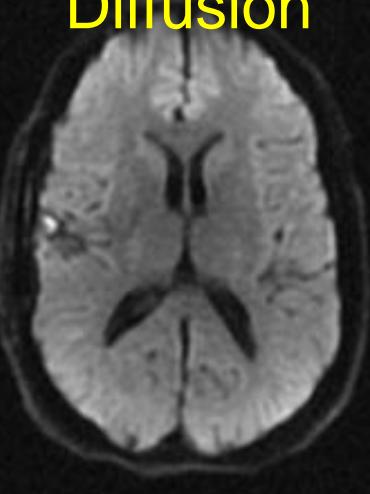
T1 no contrast



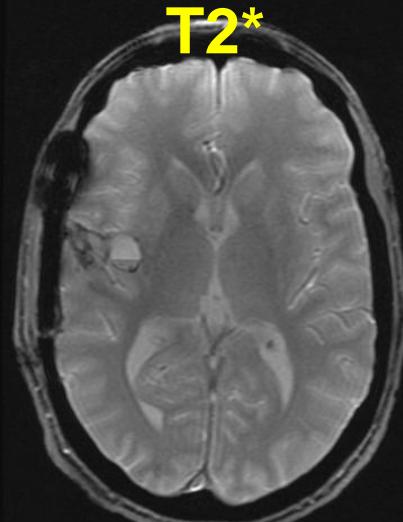
T1 contrast



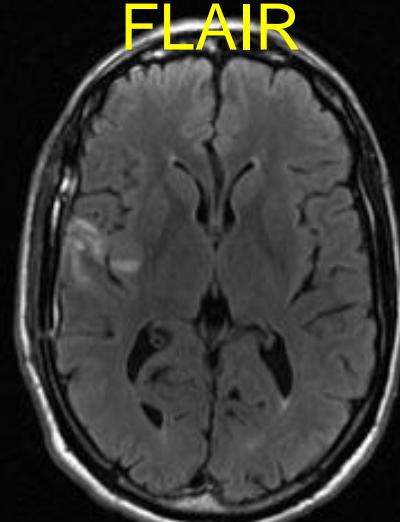
Diffusion



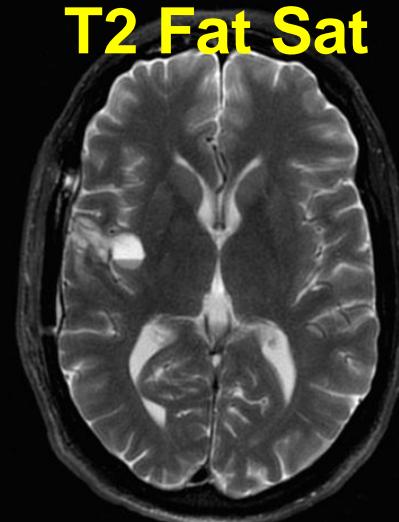
T2\*



FLAIR



T2 Fat Sat



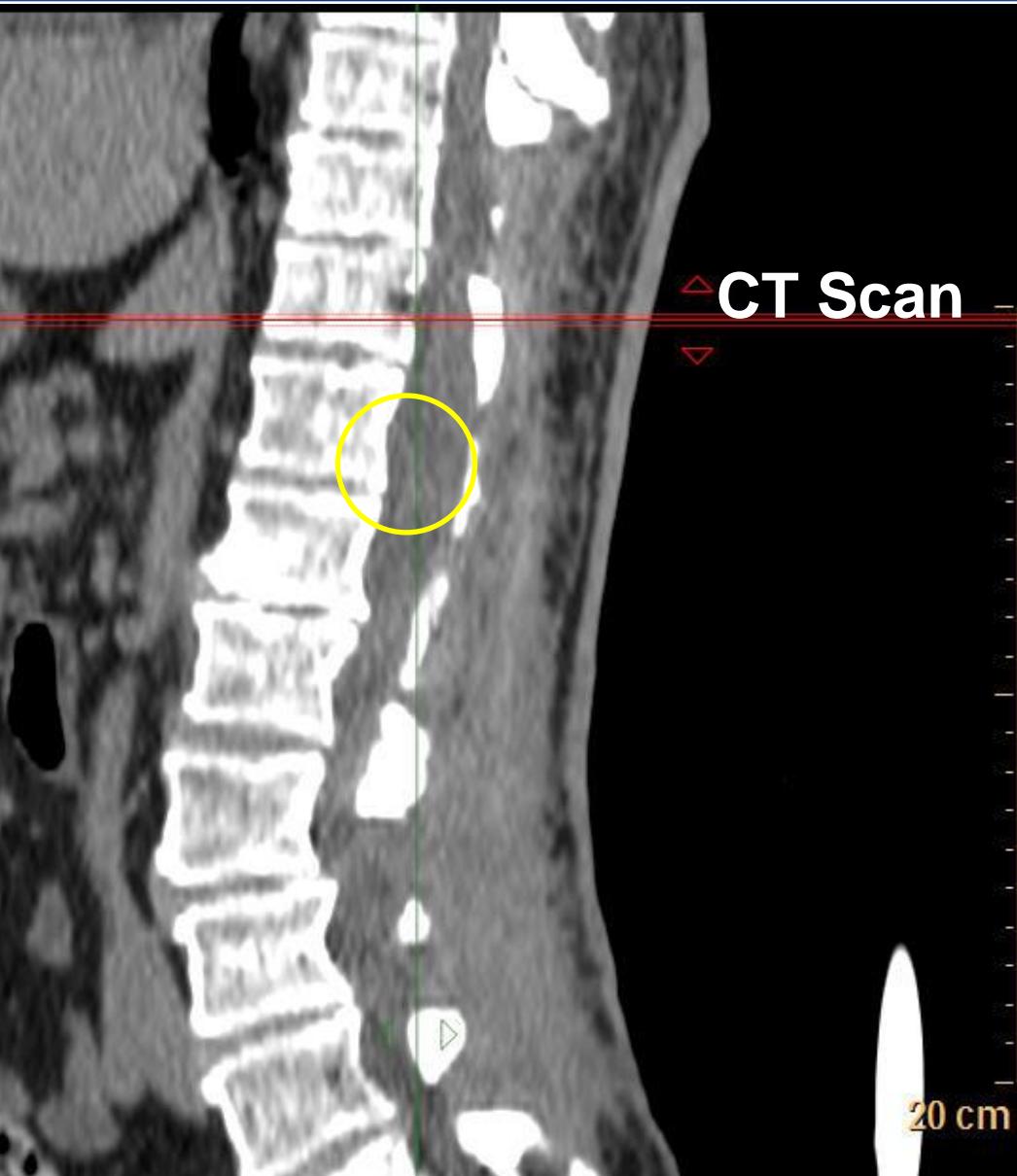


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# Metastasis – Posterior Vertebral Body



# Tumor in Spinal Canal



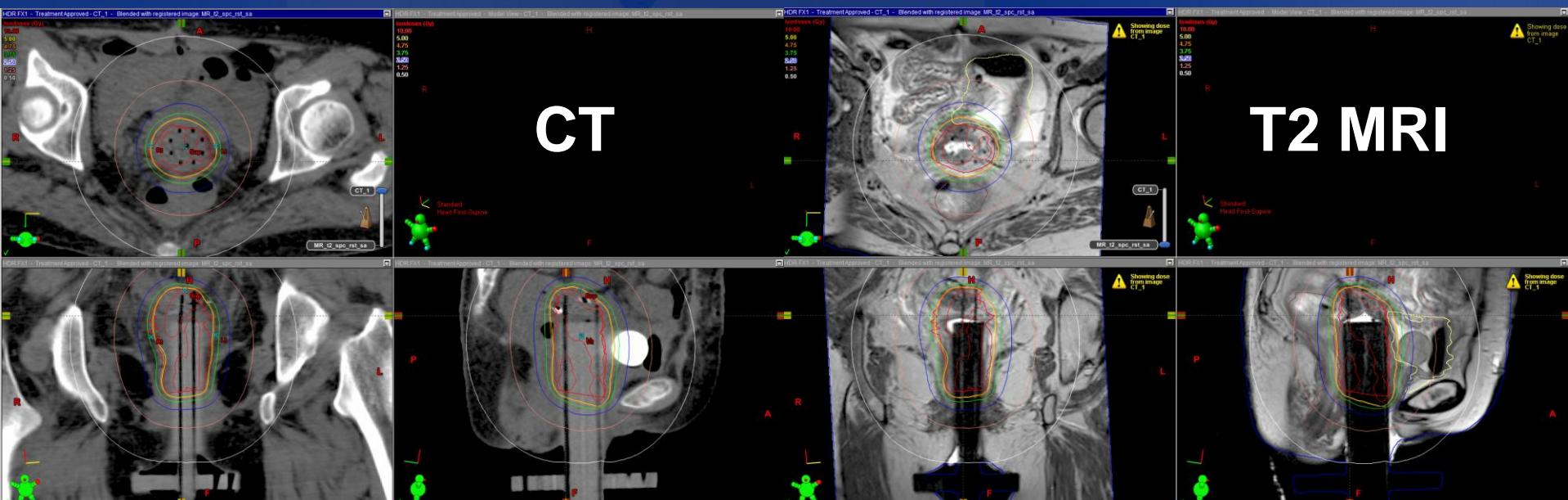
CT Scan

T1 MRI  
w/contrast



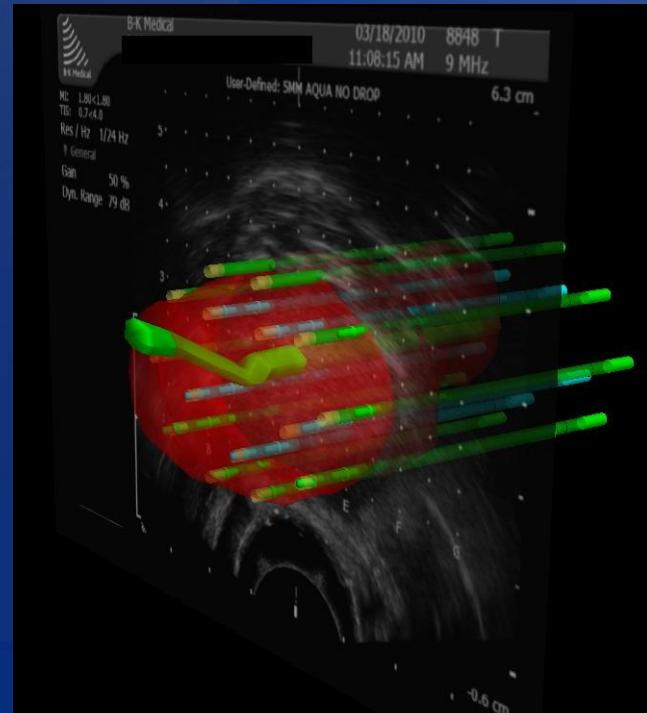
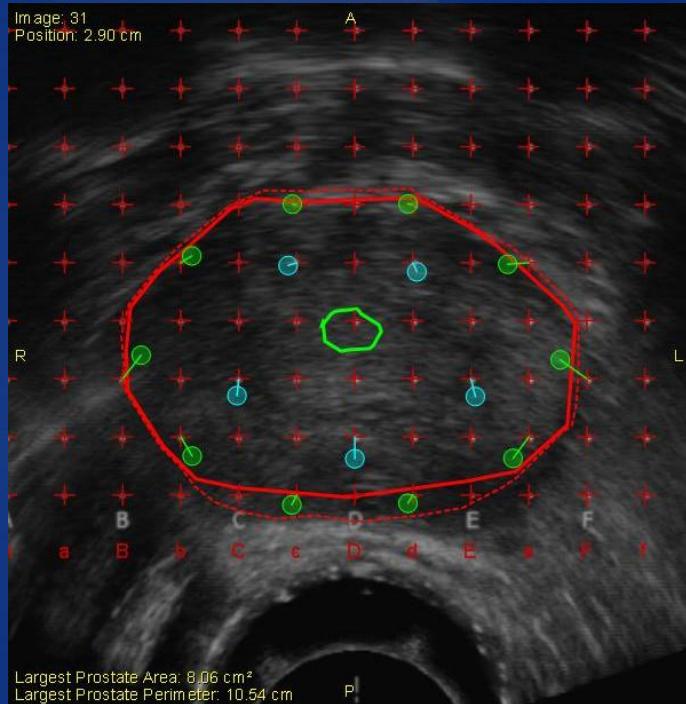
# Gyn HDR Clear Cell Carcinoma

- 54 yo Woman with T3N0M0 Clear Cell Carcinoma
- 45 Gy whole pelvis - 50 Gy to GTV using IMRT
- Boost with HDR 15Gy in 3 fx using MRI based planning.



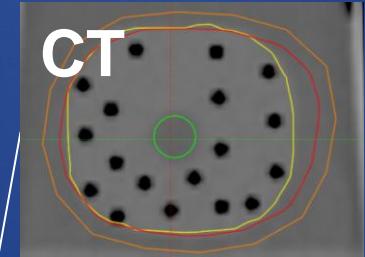
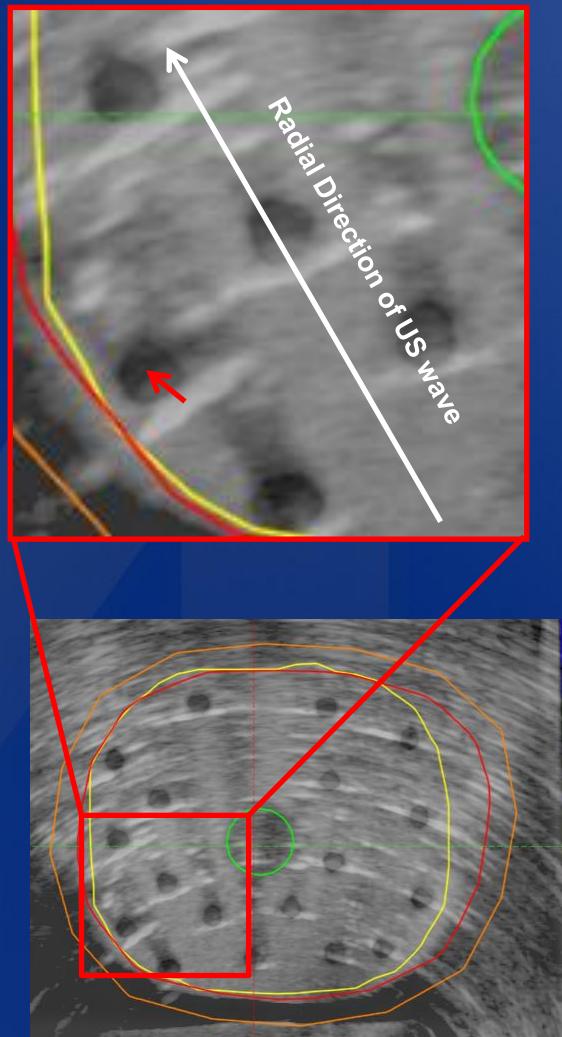
# US In Prostate Brachytherapy

- US Placement of needle
- US based treatment planning

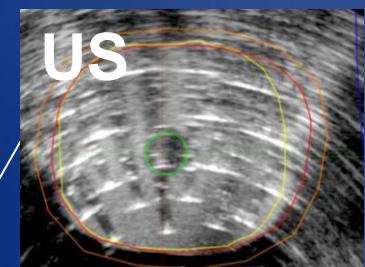


# US/CT of Prostate Phantom

- US signal is coincident with the leading edge of needle
- Potential half needle width offset when US is used to digitize position
- Error is less than 1mm



Registration & Fusion



# 4DCT Technical Explanation

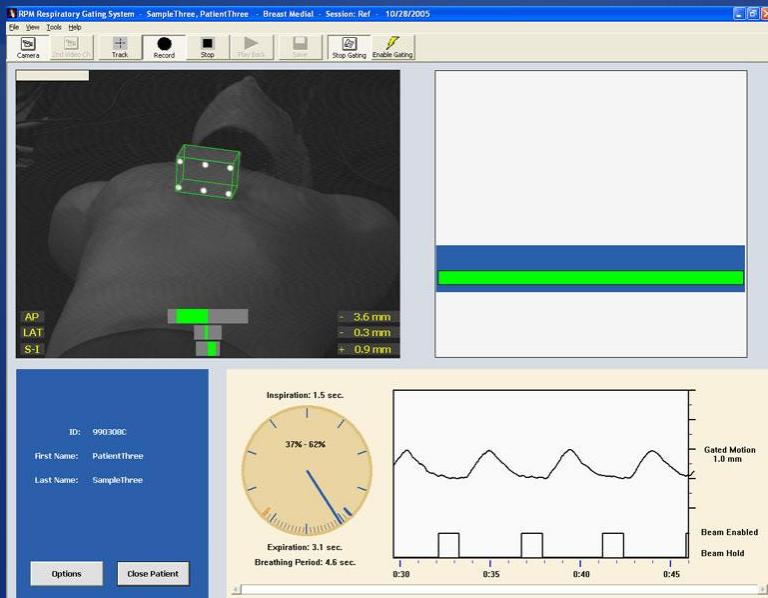
- CT movie of breathing motion
  - Respiratory correlated
  - N number of CT scans, “phases”
  - Visualize tumor motion and create ITVs for planning.

# Respiratory Signals

- Signal that indicates breathing state
- Correlated with image acquisition
- Used to sort image data
  - all inhales data together ...
- Assumption of periodic motion
  - all inhales are the same ...

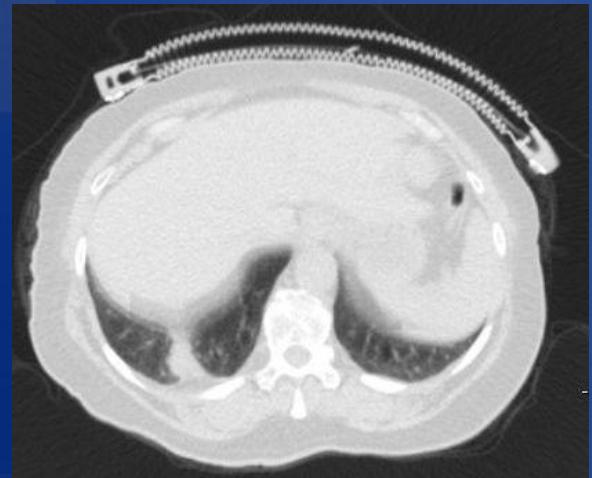
# Resp Signals: Surface Monitoring

- Varian RPM
  - Reflective marker block
  - Interfaced with 4DCT
  - Allows gating at Linac

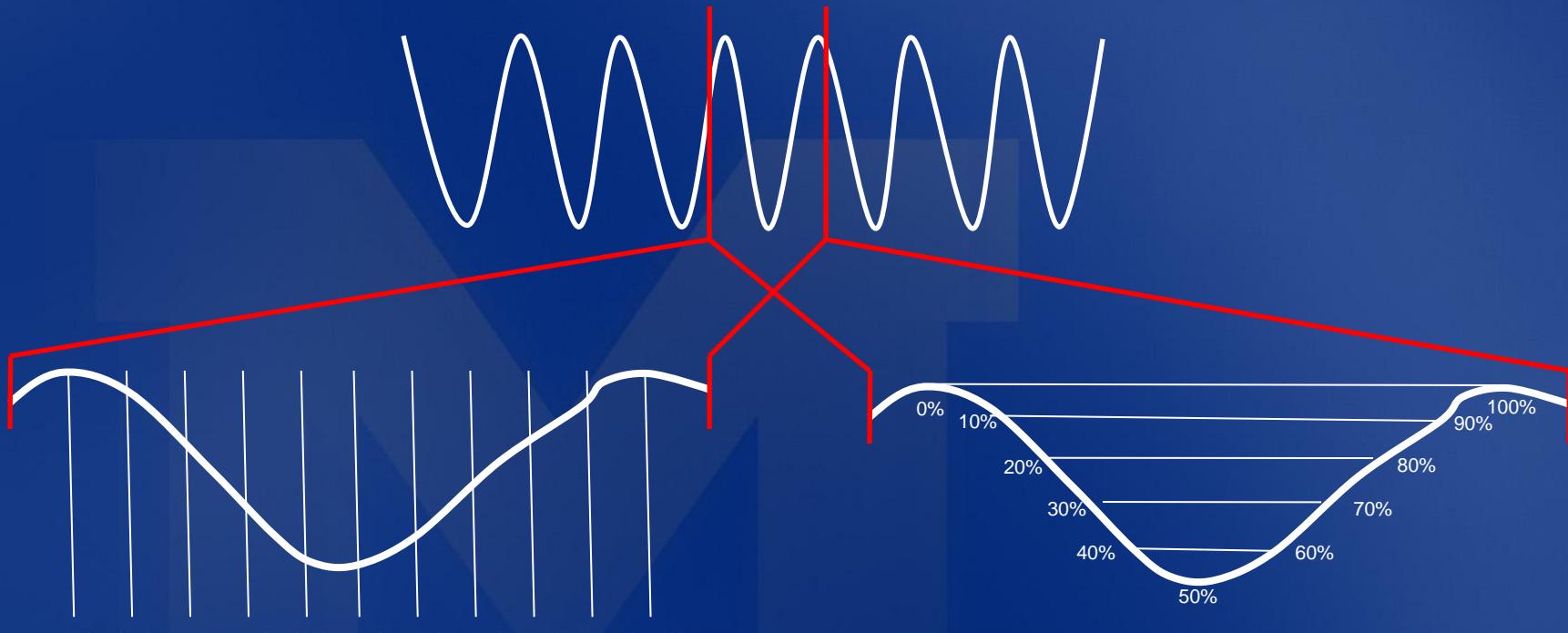


# Resp Signals: Belts

- External Bellows (Band)
  - Philips Bellows
- Inductive Band
  - Used in sleep lab



# Resp Signals: Phase vs. Amplitude



Phase

Amplitude

# 4DCT Often Not Perfect

- Motion Artifacts
- Higher dose
- Long scan times
- Contrast Difficulties



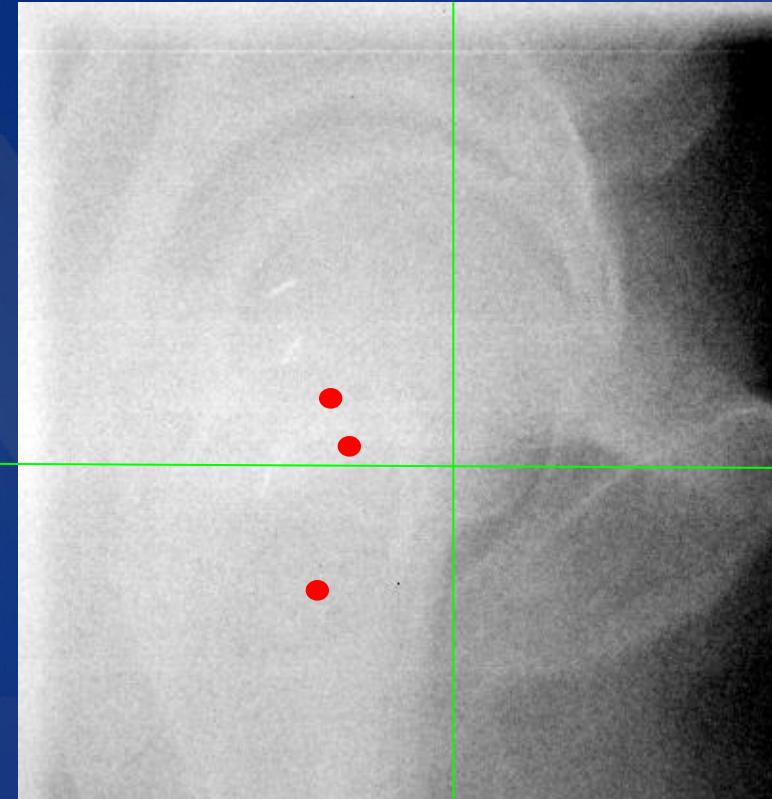
# IGRT Systems

- Ultrasound imaging
- Video – Surface imaging
- MV ortho' set
- kV OBI systems
- CBCT

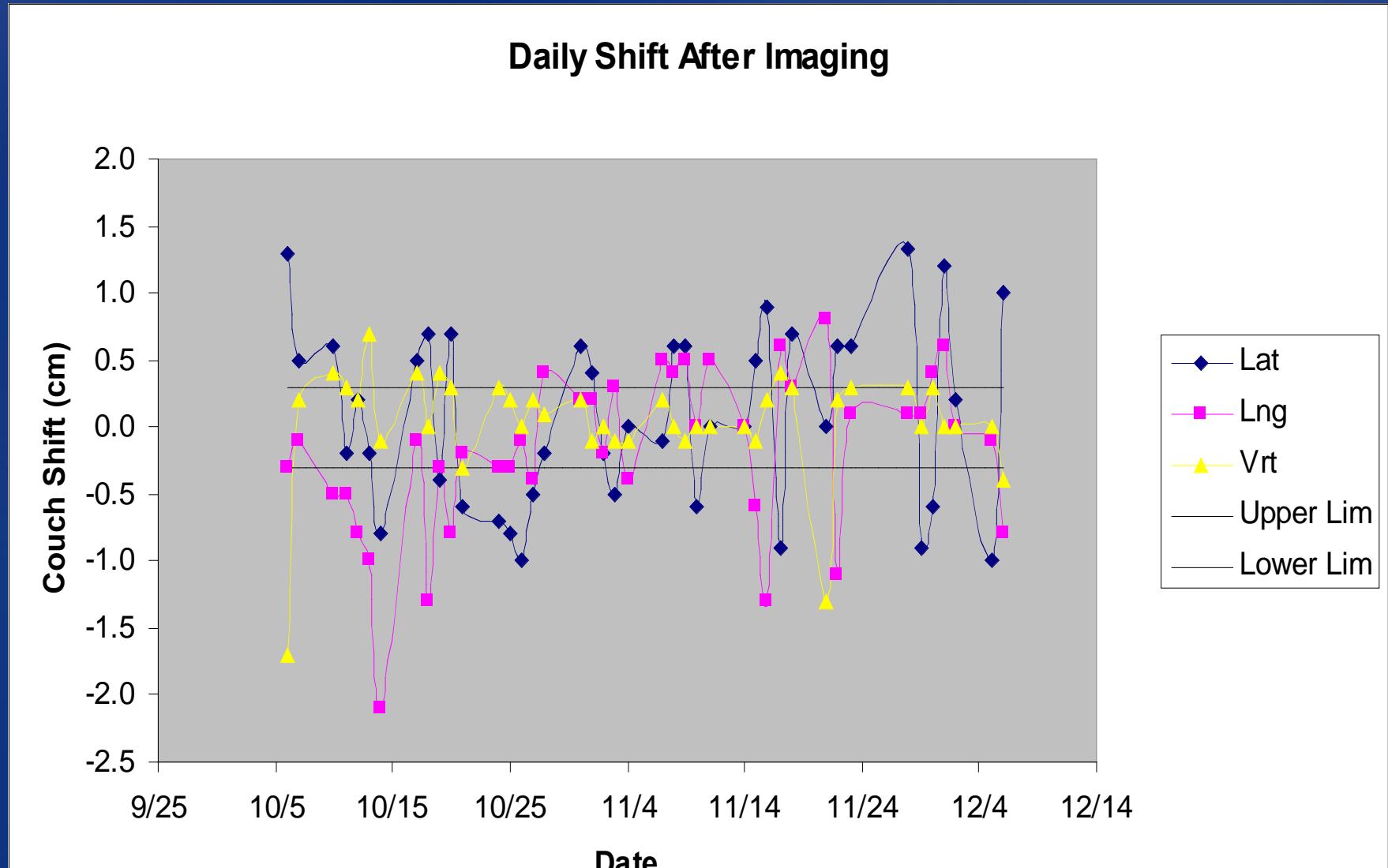
# Overall Goal

- Reproduce the position seen in simulation and planning
- Place target anatomy in the beams
- Place normal tissue outside the beams

# Systematic and Random Errors



# Systematic and Random Errors



# Positioning What Exactly?

- GTV Imaging and Targeting
  - Tumor or target can be seen and positioned.
- Surrogate Imaging for GTV targeting
  - Tumor or target cannot be seen but a suitable surrogate can

# U of Wisconsin assessment of 3D US



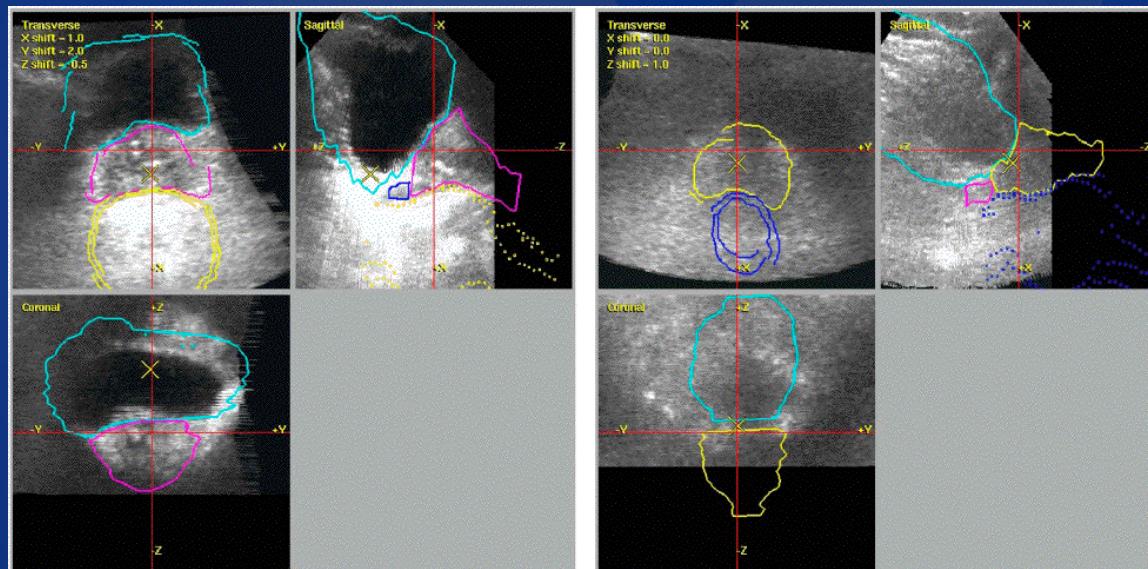
## Clinical assessment of three-dimensional ultrasound prostate localization for external beam radiotherapy

Nigel P. Orton and Hazim A. Jaradat

*Department of Human Oncology, University of Wisconsin, Madison, Wisconsin 53792*

Wolfgang A. Torné<sup>a)</sup>

*Departments of Human Oncology and Medical Physics, University of Wisconsin, Madison, Wisconsin 53792*



Orton et al. Clinical assessment of three-dimensional ultrasound prostate localization for external beam radiotherapy. Medical physics (2006) vol. 33 (12) pp. 4710-7

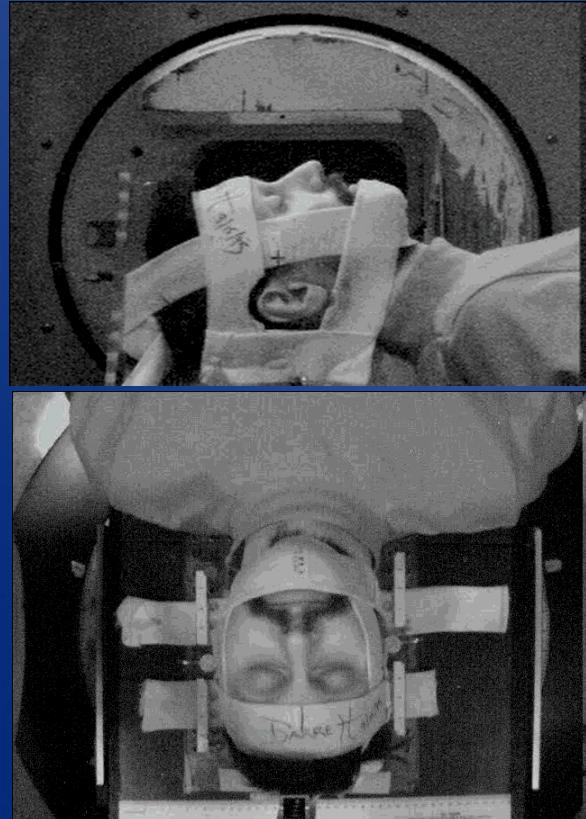
# U of Wisconsin assessment of 3D US

- Compare 3D US to Tomo' MVCT
  - US-MVCT vector average  $3.1 \pm 1.3\text{mm}$
  - Skin-MVCT vector average  $5.1 \pm 2.1\text{mm}$
- Intrafraction movement
  - $1.9 \pm 1.0\text{mm}$
- Interuser Variation
  - Experienced users can obtain similar results

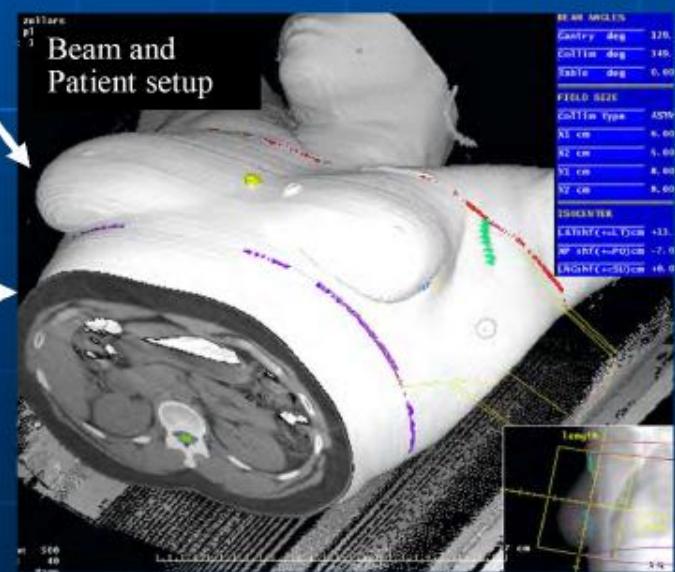
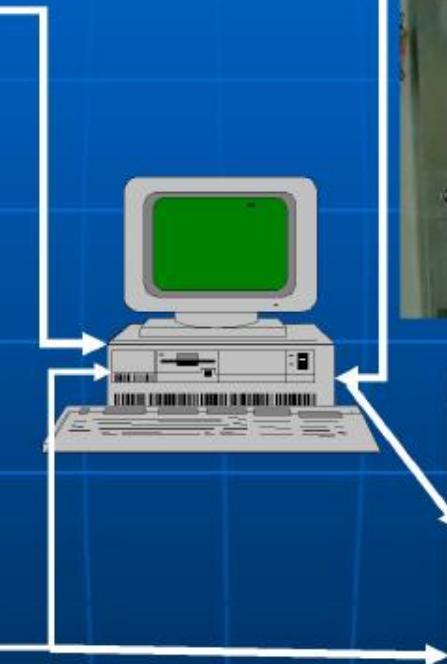
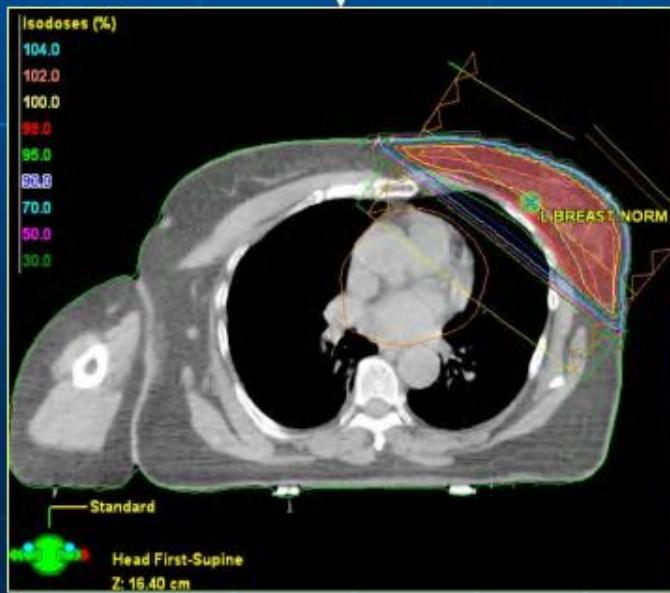
Orton et al. Clinical assessment of three-dimensional ultrasound prostate localization for external beam radiotherapy. Medical physics (2006) vol. 33 (12) pp. 4710-7

# Video and Surface Positioning

- Video or Surface images to determine positioning error
- Skin surface as surrogate anatomy for target at depth
- No dose, highly interactive



# An Integrated Real-time Image-guided adaptive RT of Breast Cancer



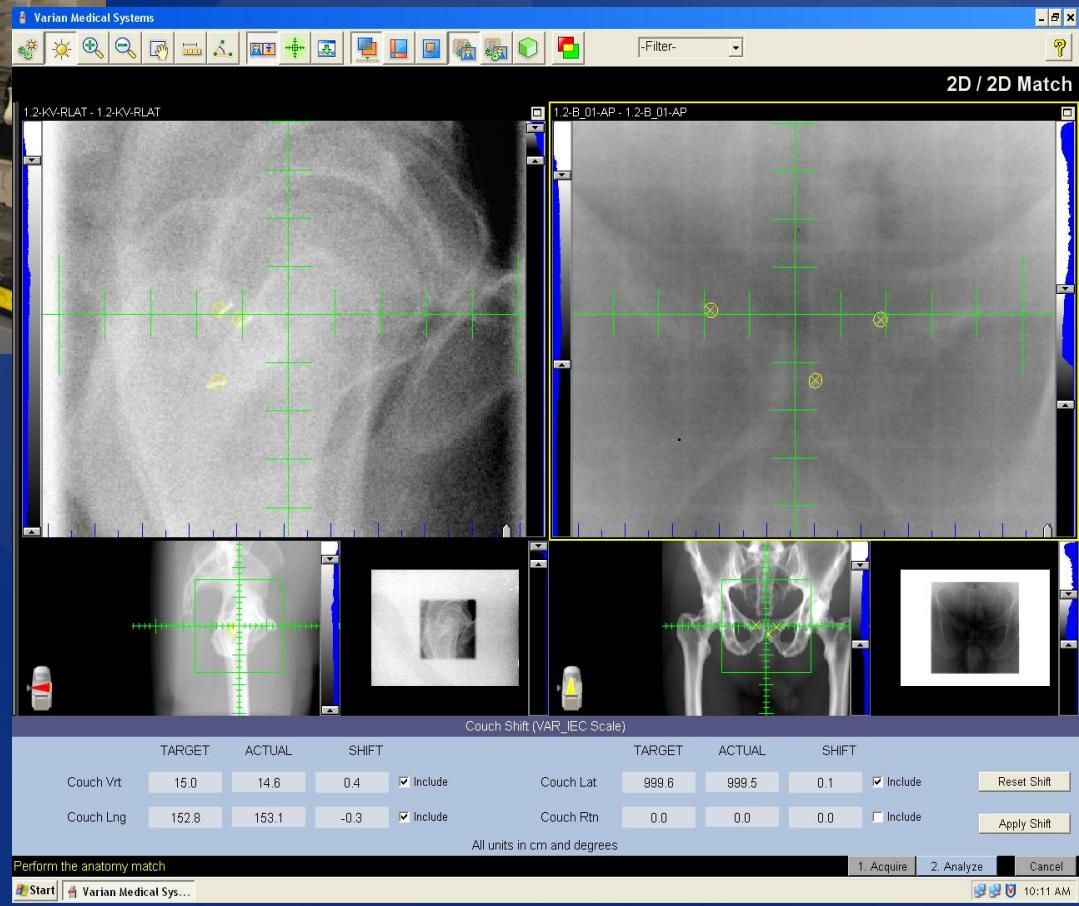
# Video and Surface Publications Recent

- Spadea et al. Patient set-up verification by infrared optical localization and body surface sensing in breast radiation therapy. Radiotherapy and oncology (2006) vol. 79 (2) pp. 170-8
- Bert et al. Clinical experience with a 3D surface patient setup system for alignment of partial-breast irradiation patients. Int. J. Radiat. Oncol. Biol. Phys. (2006) vol. 64 (4) pp. 1265-74
- Li et al. Real-time 3D-surface-guided head refixation useful for fractionated stereotactic radiotherapy. Medical physics (2006) vol. 33 (2) pp. 492-503
- Liu et al. Accurate calibration of a stereo-vision system in image-guided radiotherapy. Medical physics (2006) vol. 33 (11) pp. 4379-83
- Laura I Cerviño PhD et al. (2012). Initial clinical experience with a frameless and maskless stereotactic radiosurgery treatment. *PRRO*, 2(1), 54–62. doi:10.1016/j.prro.2011.04.005

# X-Ray Imaging

- Gantry Mounted kV System
  - Gantry rotation for biplane imaging
  - Allows for Cone Beam CT
- Room Mounted kV Systems
  - Simultaneous biplane imaging
  - Tracking during treatment

# Varian OBI with CBCT



Perform the anatomy match

 Start |  Varian Medical Sys...

1. Acquire | 2. Analyze | Cancel

10:11 AM

# Elekta Synergy with Volume View





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# Brain Lab Exac Trac





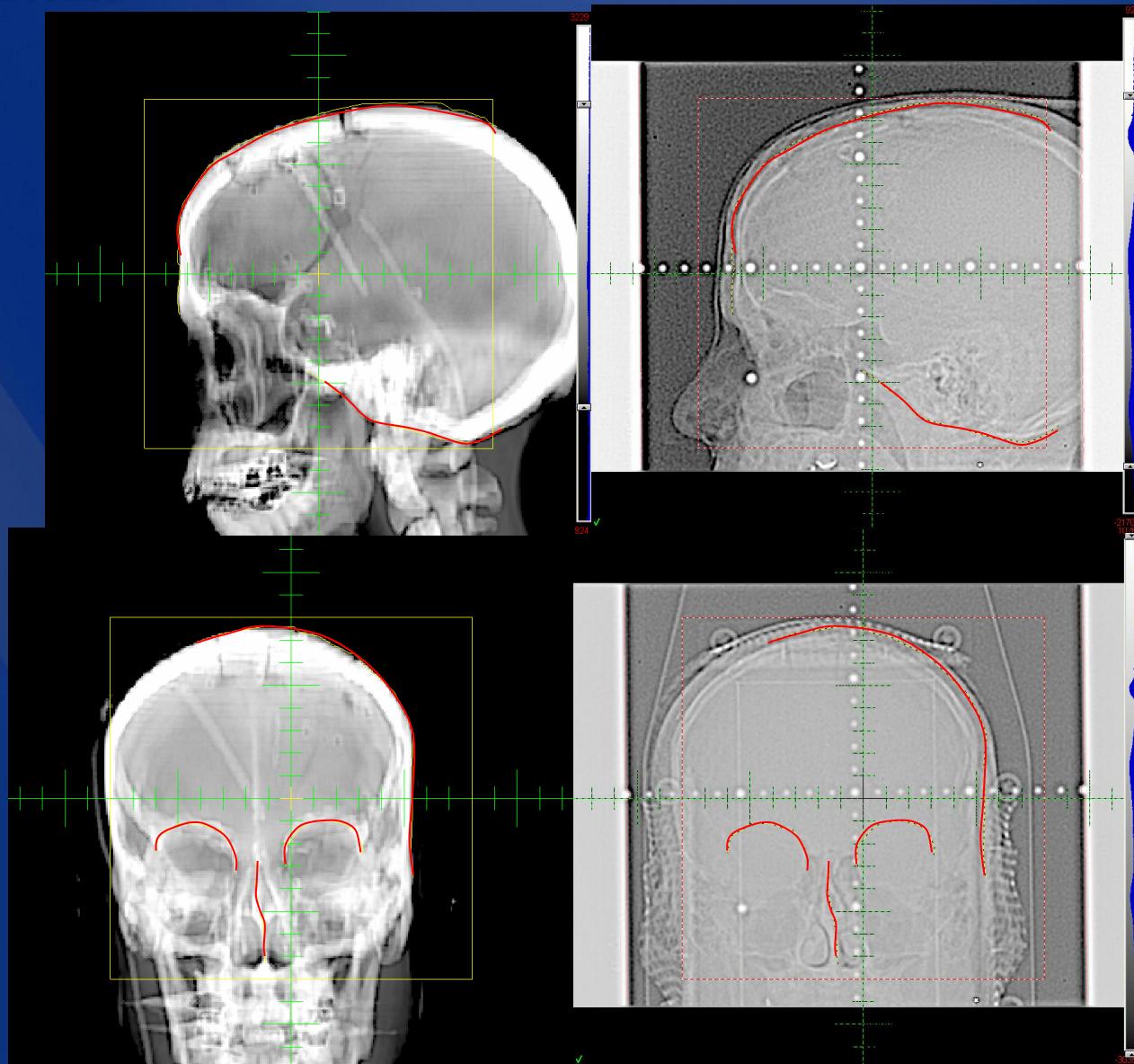
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# MV Brain

**Rotation  
In/Out  
Depth**

**Base of Skull  
Frontal or Parietal bone**

**Left/Right  
Nasal Septum  
Medial Orbita  
Lateral Skull**



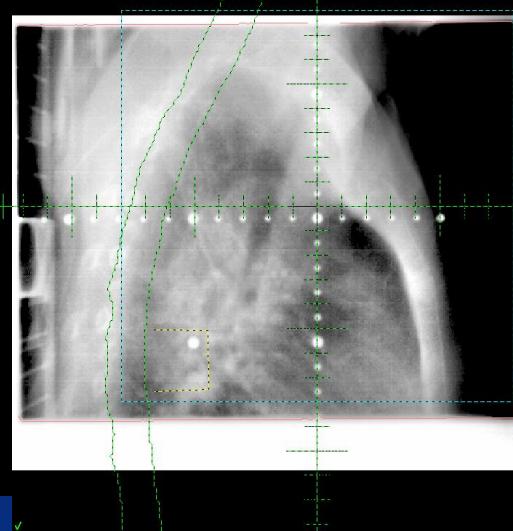
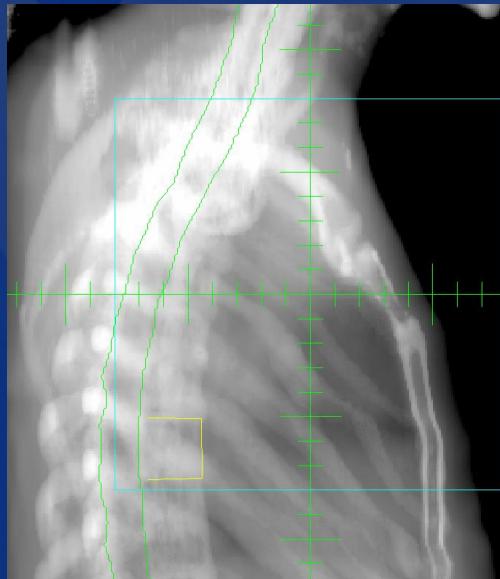
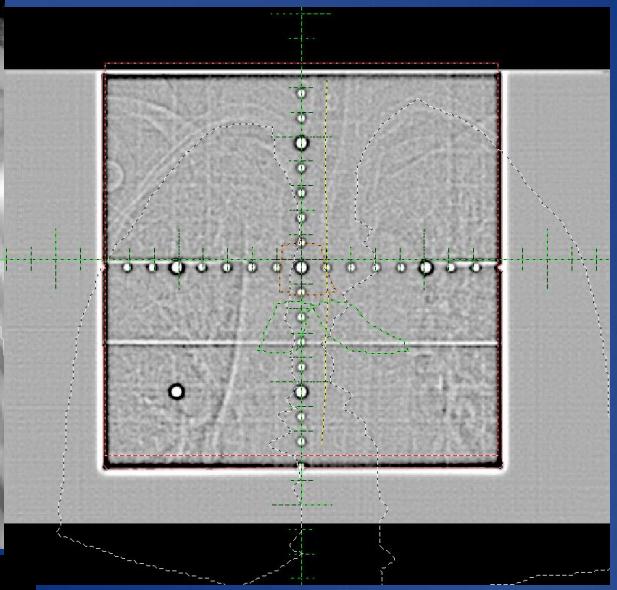
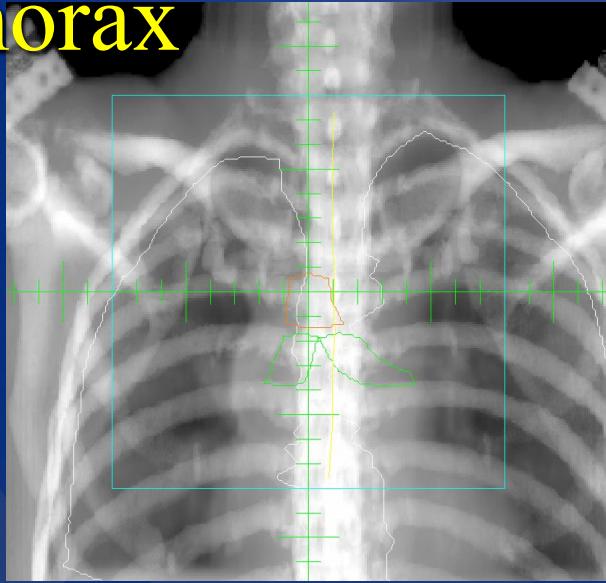


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**Left/Right**  
**In/Out**  
**Carina**  
**Spine**

**In/Out**  
**Depth**  
**Spinal Body**  
**Spinal Cord**

# MV Thorax





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# Prostate with Markers





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H&N

Varian Medical Systems

-Filter-

2D / 2D Match

8.1-KV-AP - 8.1-KV-AP

8.1-B\_01-LLAT - 8.1-B\_01-LLAT

Couch Shift (VAR\_IEC Scale)

	TARGET	ACTUAL	SHIFT		TARGET	ACTUAL	SHIFT		
Couch Vrt	14.5	14.6	-0.1	<input checked="" type="checkbox"/> Include	996.2	996.2	0.0	<input checked="" type="checkbox"/> Include	Reset Shift
Couch Lng	61.3	61.3	0.0	<input checked="" type="checkbox"/> Include	0.0	0.0	0.0	<input checked="" type="checkbox"/> Include	Apply Shift

All units in cm and degrees

Perform the anatomy match

1. Acquire 2. Analyze Cancel

Start Varian Medical Sys... 9:00 AM

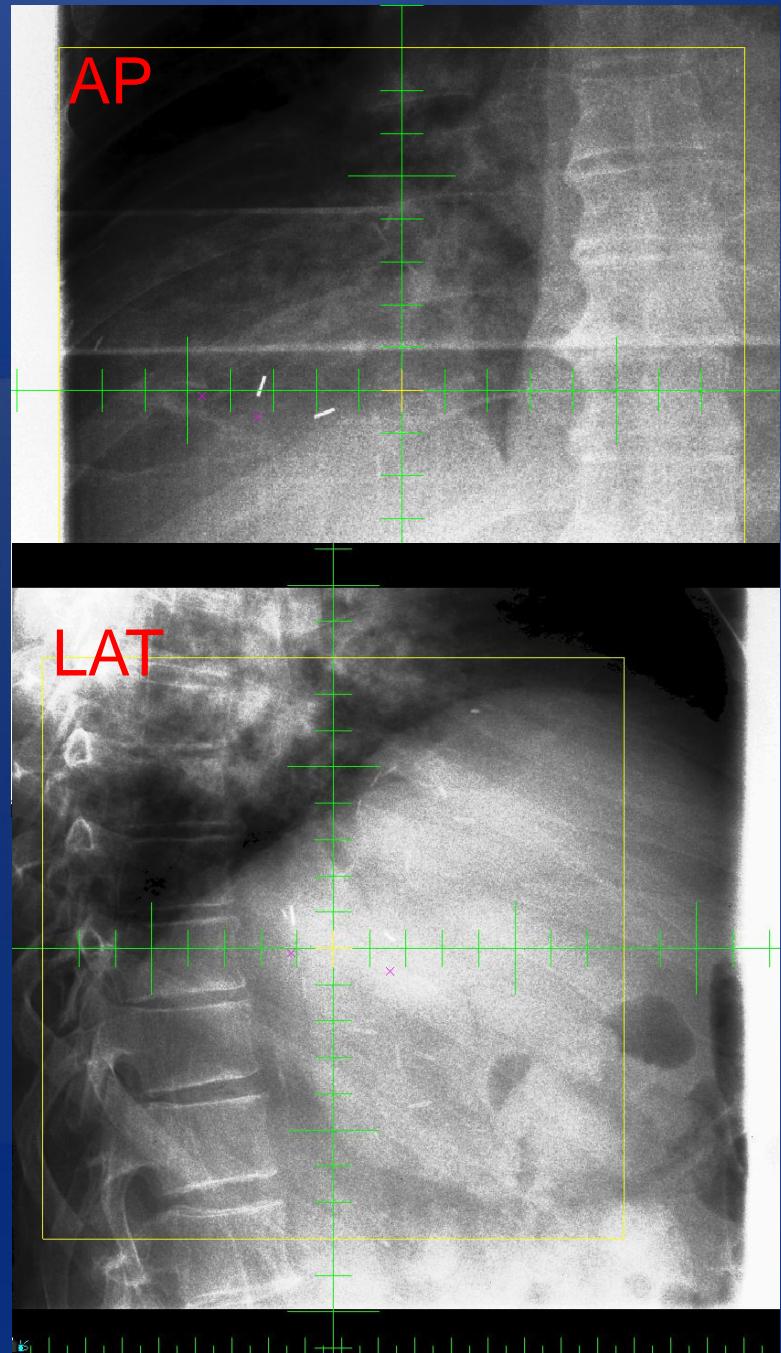
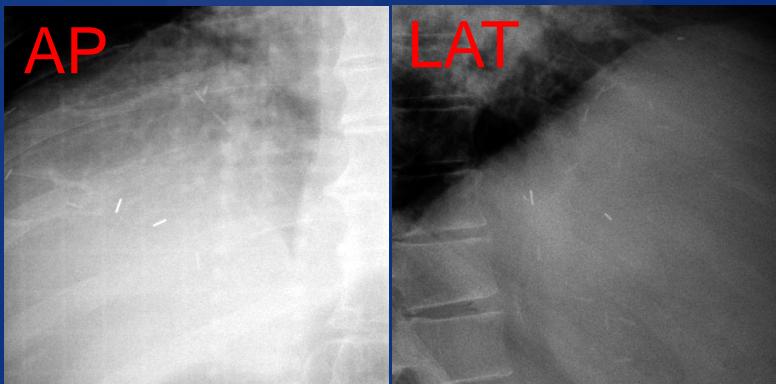
# Liver Stereo

ABC Exhale Breath hold  
imaging and treatment

Tumor Not visible on CT

Marker Positions from 3D CT  
Planning

Daily Position

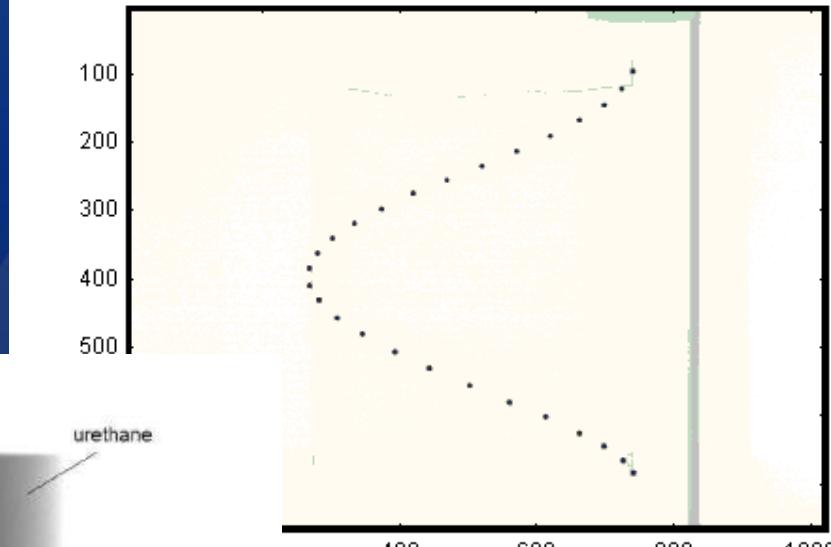


# Cone Beam CT

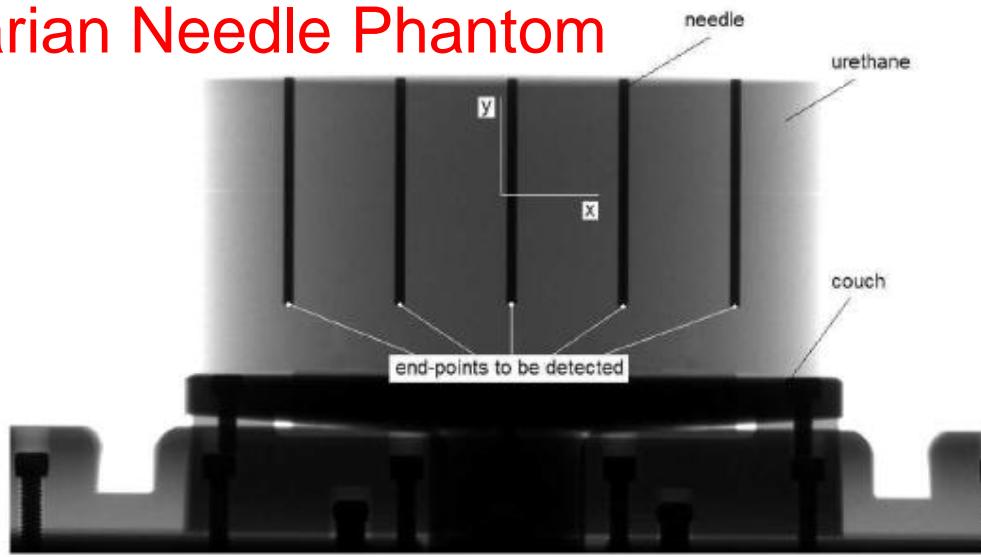
- Calibration and Isocenter
- kV Clinical Cases
  - Spine
  - Lung
- Artifacts
- MV CBCT

# CBCT Geometric Calibration

Home Made Spiral BB Phantom



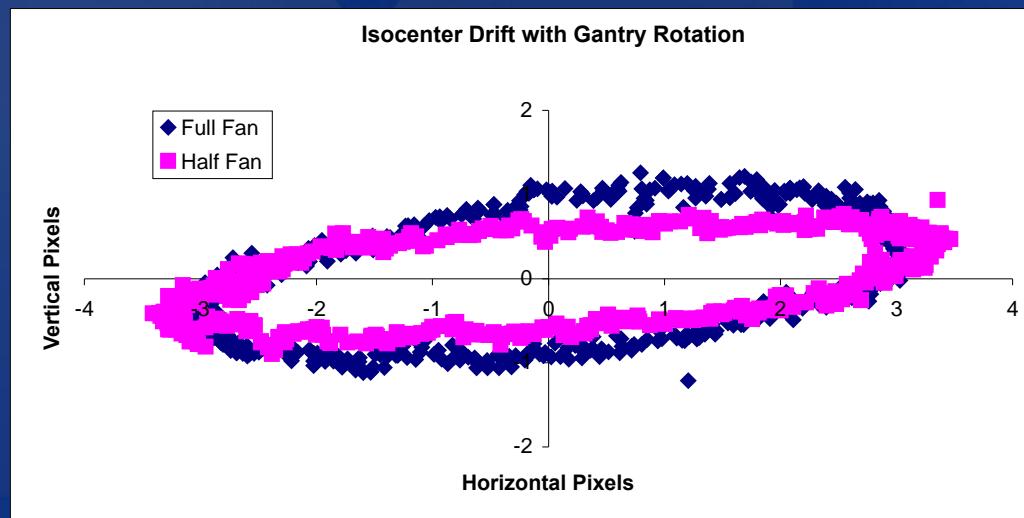
Varian Needle Phantom



Matsinos et al. The geometric calibration of cone-beam imaging and delivery systems in radiation therapy. Arxiv preprint physics (2006)

# CBCT Geometric Calibration

- Correct Sag in IDU via software
- Confirm that IDU sag can be ignored



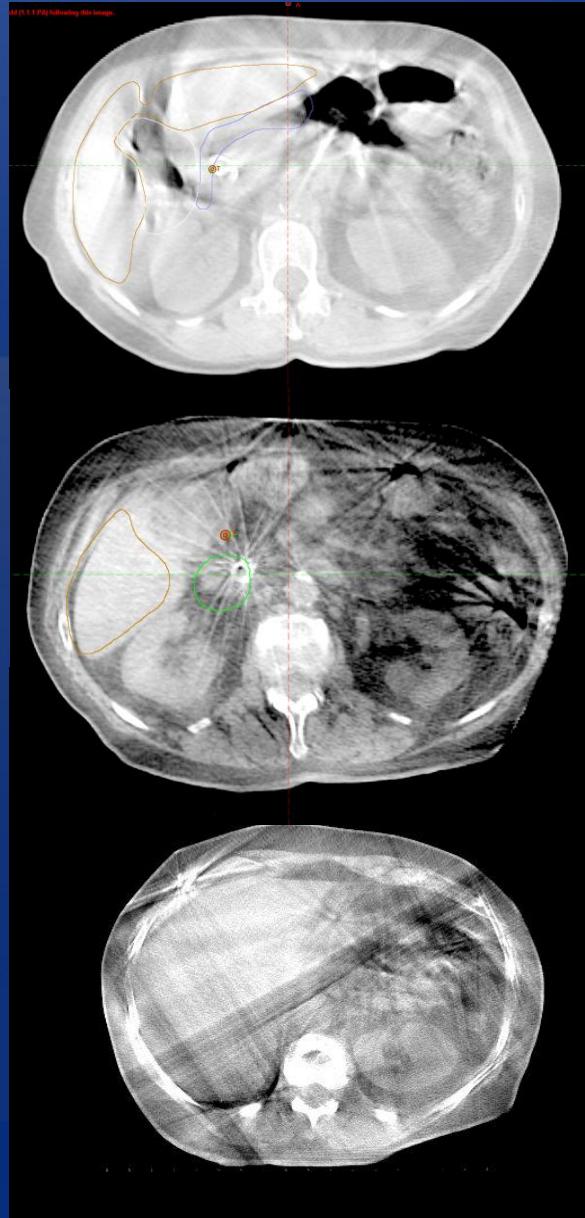
# CBCT Dose Per Image

Author	Year	System	Deep Dose (cGy)	Shallow (cGy)
Son et. al.	2008	XVI	0.15-2	0.15-4.5
Son et. al.	2008	Varian	1.8-8.5	1.8-8.5
Ding et. al.	2008	Varian	3-12	
Wen et. al.	2007	Varian	3-4	2.5-6.0
Kan et. al.	2007	Varian	0-11	0-12
Gayou et. al.	2007	MVision	2-10	
Morin et. al.	2007	MVision	5-10	
Hansen et. al.	2006	MVision	4.5	
Létourneau et. al.	2005	XVI	1.5-5	2.3-7.5

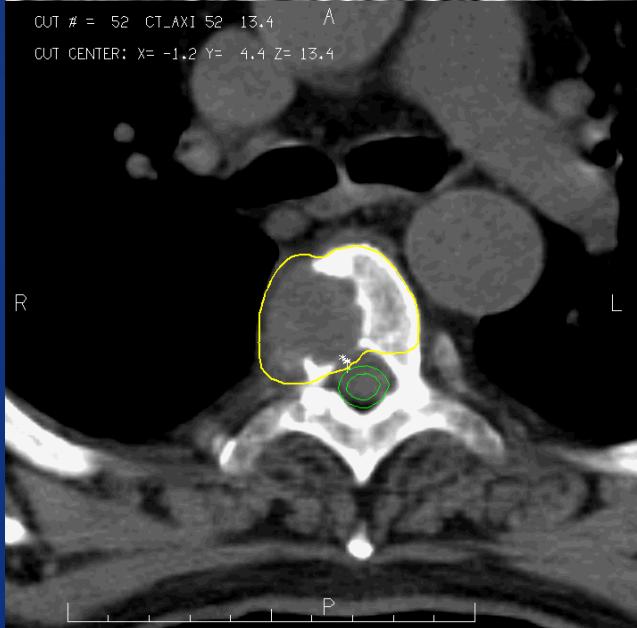
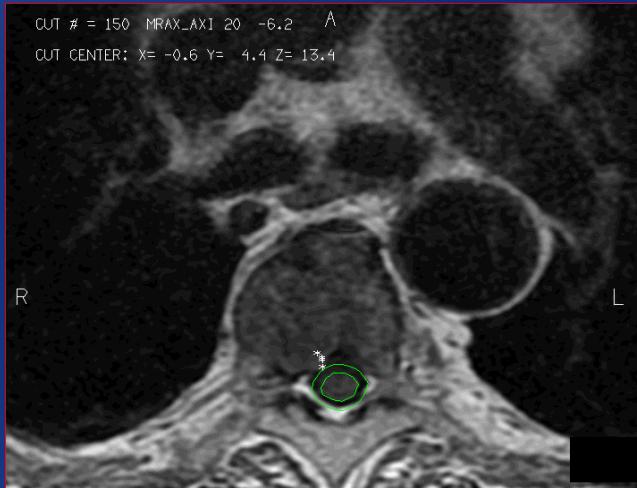
\* Compare with single 3MU MV image dose of 2.4 cGy

# CBCT Artifacts

- Movement during 60 second scan time creates streak artifacts
- Small motions of high Z objects
- Gas pockets, low Z, moving during scan
- Inconsistent projection data
- Reconstruction has to wing it



# CBCT Spine Stereo



- SBRT treatment to vertebral body
  - 16 Gy fraction
  - 70% Isodose line

Courtesy of Annette Kretzler



University of Michigan  
Medical School

# Alignment Cone Beam CT



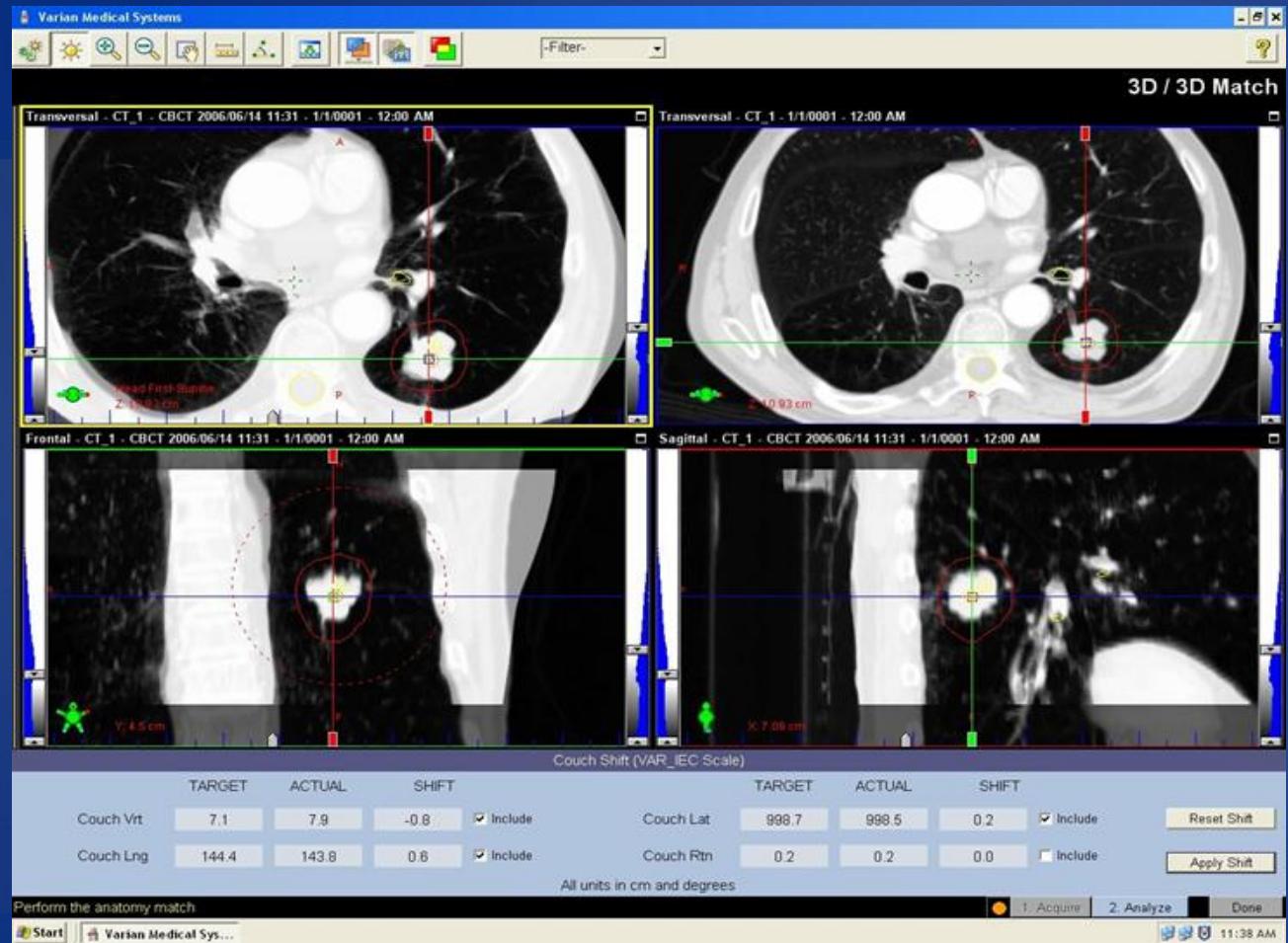
# CBCT Lung

60 second scan time

ABC Breath Hold →  
2 – 4 Breath  
Holds

Exhale Breath  
Hold

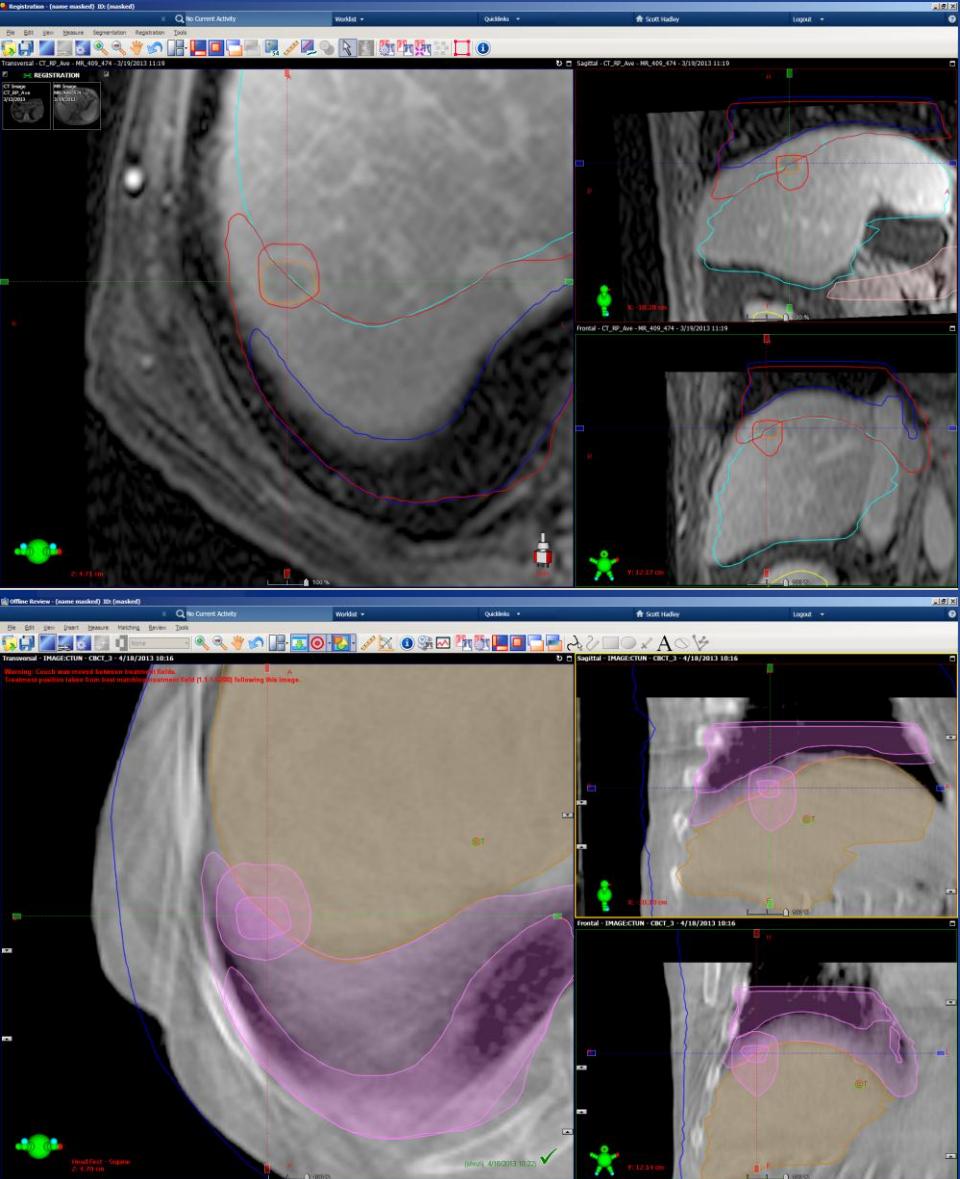
Inhale Breath  
Hold



Courtesy of James Balter

# Free Breathing Liver SBRT

- 4DCT for planning
- GTVs from exhale MRI
- Registration to exhale phase of 4DCT
- ITV expansion from 4DCT motion
- Tx IGRT using FB CBCT and avg from 4DCT



# X-ray Summary

- Gantry Mounted Systems
  - Biplane imaging with gantry rotation
  - Allow CBCT for 3D set of soft tissue
  - Imaging concurrent with treatment is not effortless
- Room Mounted Systems
  - Biplane imaging made easy
  - CBCT not possible
  - Imaging can be concurrent with treatment