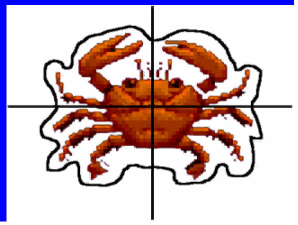
Image guided Radiation Therapy (IGRT) – a perspective

James Balter, Ph.D.
University of Michigan

Has financial interest in Calypso Medical Technologies



What is image guidance?

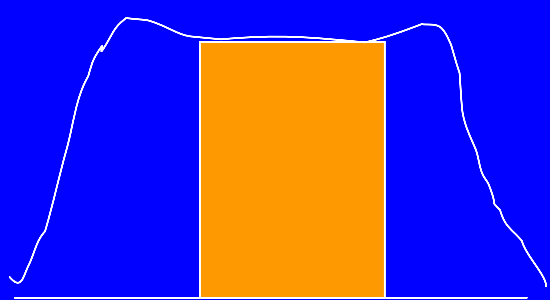
Broadly stated, IGRT involves any use of imaging to aid in decisions in the radiotherapy process

- Decision of whether/how to treat
- Delineation of structures of interest
- Aid in positioning, verification, and monitoring
- Assessment and prognosis of outcome

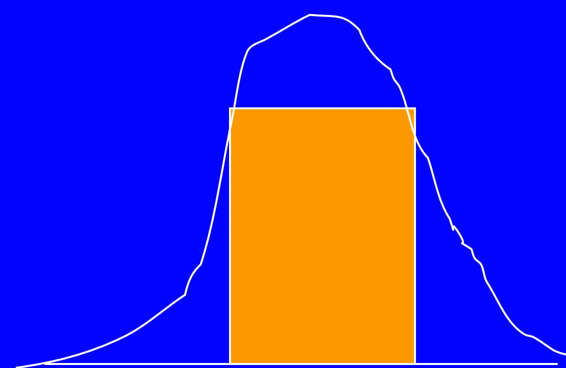
Although significant work is happening in all areas, a few areas have received the most recent attention

- in-room imaging and localization techniques
- “4D” characterization and management for breathing
- “molecular” imaging
- “adaptive” therapy

Need for accurate target definition!

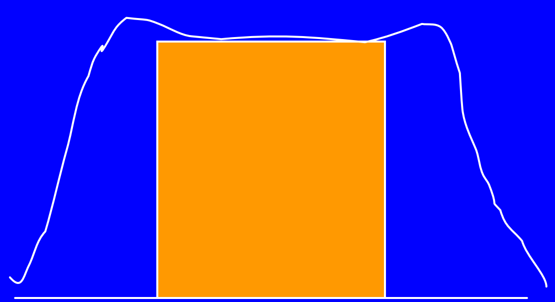


Conventional

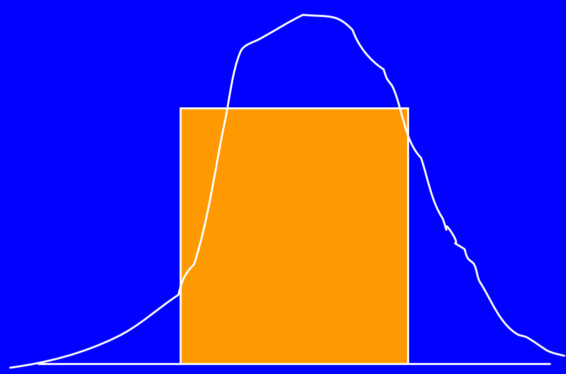


High precision

Need for accurate target definition!



Conventional



High precision

IGRT and optimization - 1988

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on be-

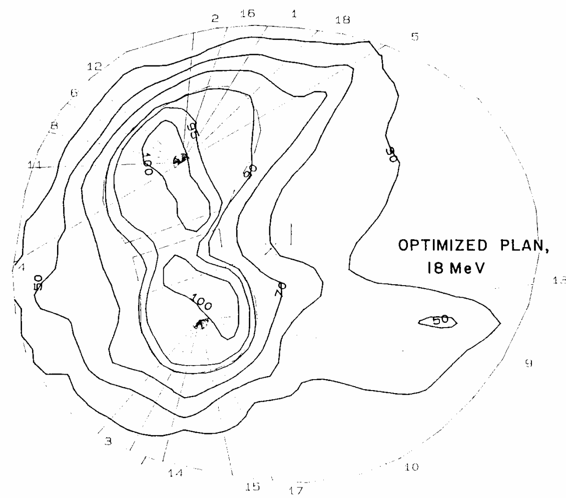


Figure 11
Using an optimization program, this irregular target volume is almost exactly covered by the 90% isodose line and the dose at the center, marked by the X, is limited to 50%.

distribution is achieved with angled beams. Here, the need for tissue compensation overrides the need to compensate for the expected hot spot at the apex of the overlap region. Thus, the wedges must be reversed from their usual placement.

Finally, Figure 11 shows an example of what can be achieved by optimization programs. In this case, the target volume is almost exactly covered by the 90% isodose line and the dose at the center, marked by the X, was limited to 50%. This 18 field plan with two isocenters and field sizes conforming to the shape of the target volume can be executed by some modern computer controlled treatment machines with only one patient setup.

Work is underway at some centers to develop schemes for optimizing treatments which take into account the variation in the size and shape of the target volume in three dimensions. Although the three dimensional target volume has an irregular shape in most cases, radiotherapists frequently draw the target area as a circle, square, or rectangle, since those are the shapes of the isodose curves usually obtained by standard plans. The use of optimization would allow the radiotherapist to define the target volume more precisely, based on the characteristics of the tumor rather than on the characteristics of the treatment machine.

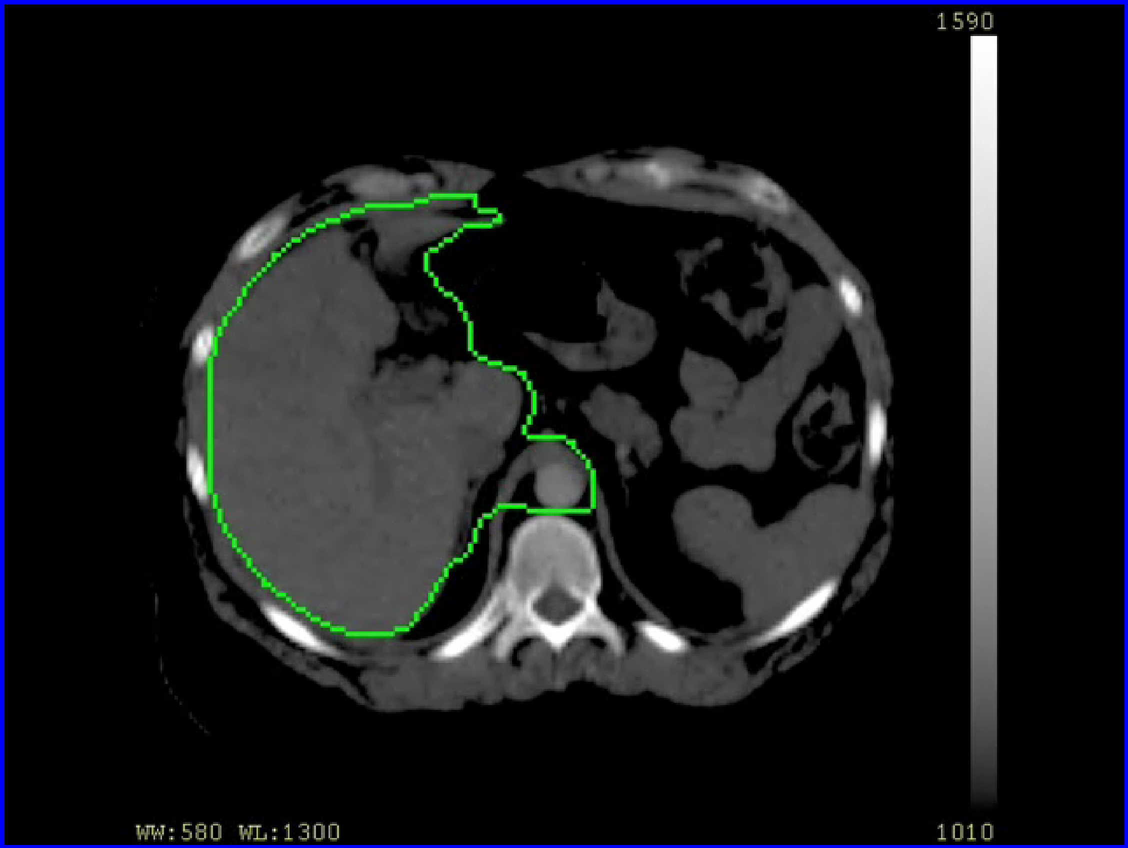
Imaging for target definition

CT is the most dominant imaging modality

While CT provides useful information, a number of parameters need consideration for optimizing the use of this modality

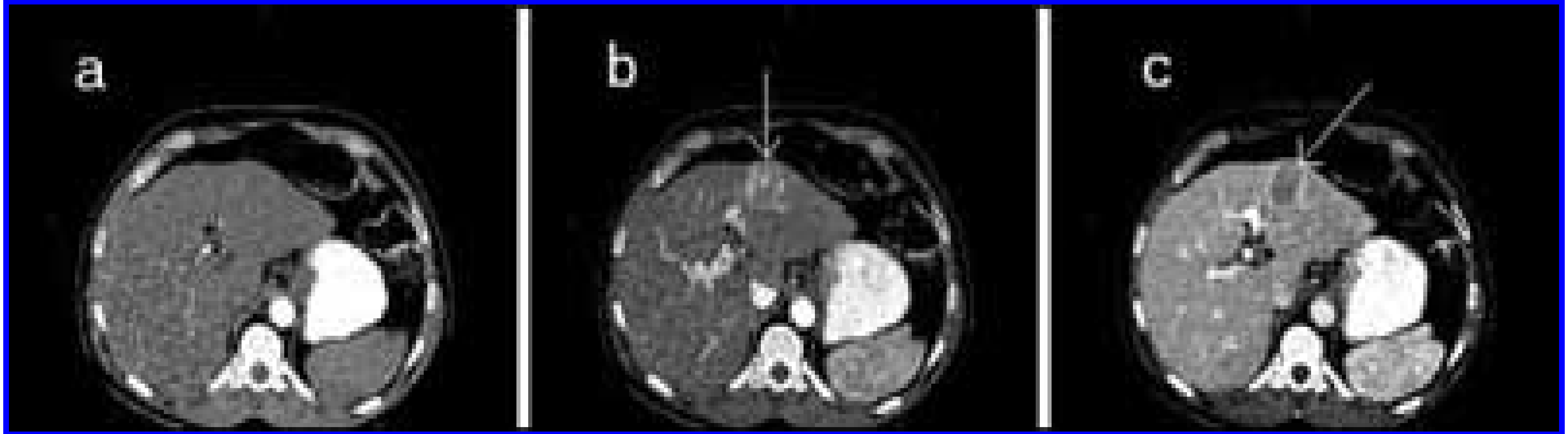
- Resolution versus SNR
- Contrast and contrast timing
- Effects of geometry and heterogeneities on image quality

Dynamic contrast enhancement – time series of differential uptake in the liver



Y. Cao, University of Michigan

Optimizing contrast - timing



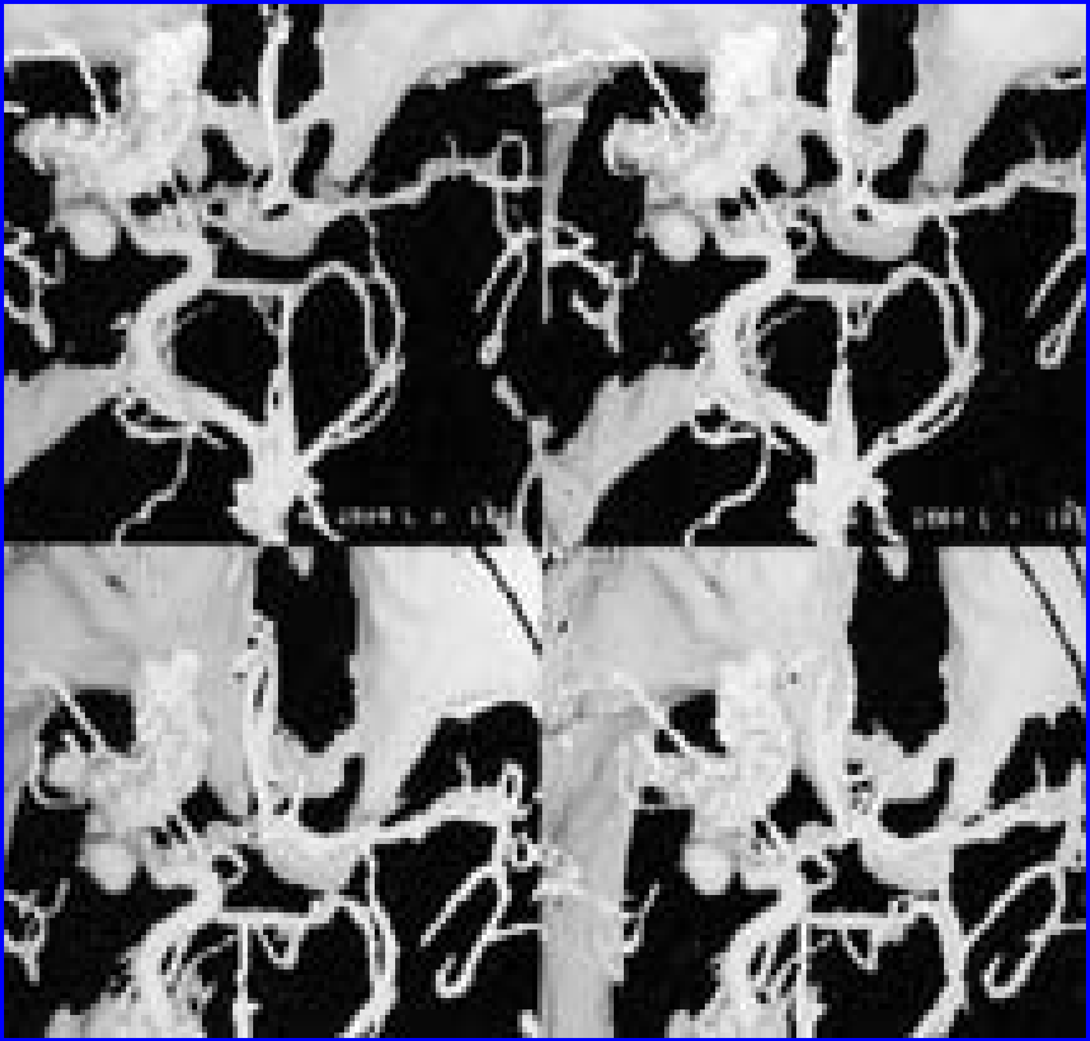
Early Arterial

Late Arterial

Venous

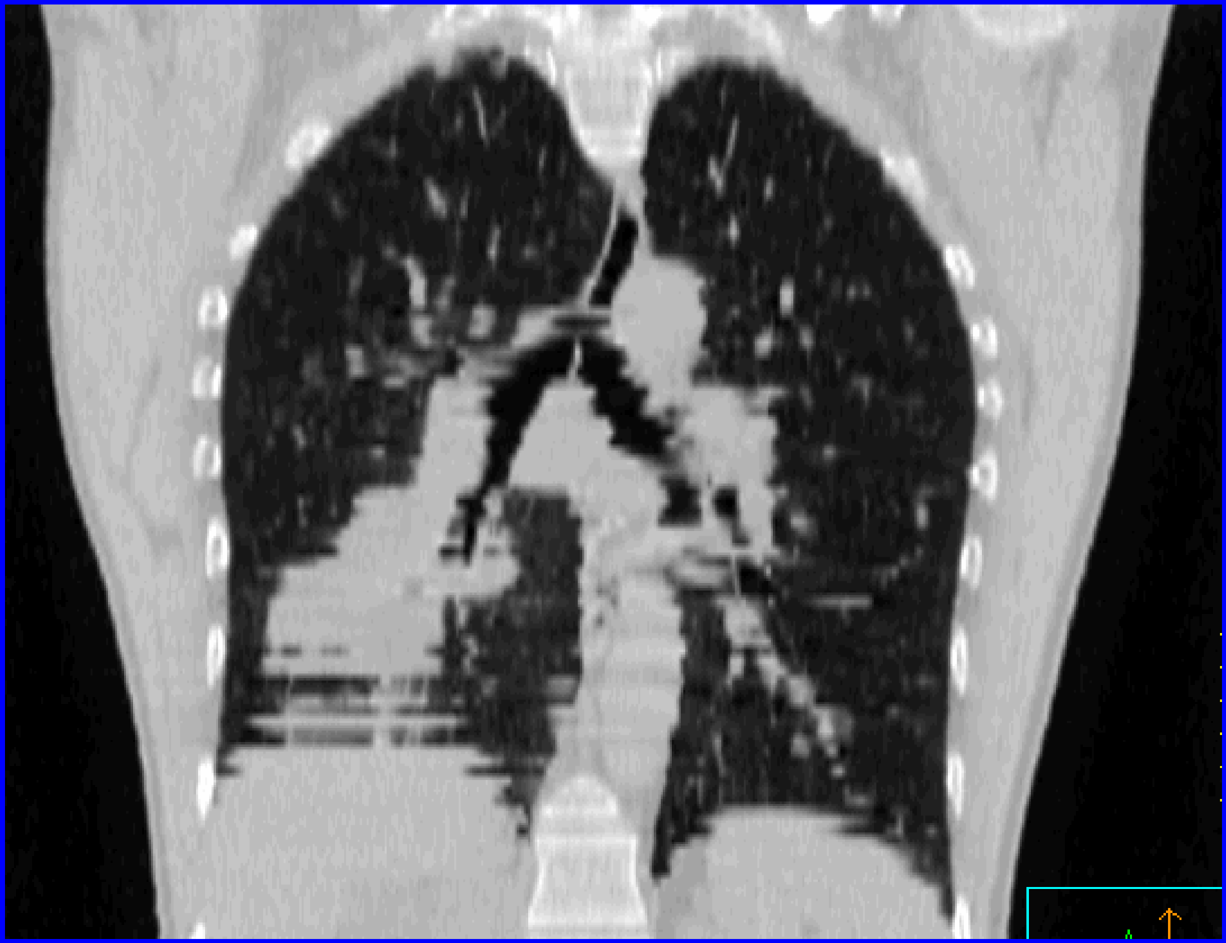
Hepatocellular Carcinoma: Optimal Contrast Strategies for Detection and Staging Using Multislice CT
By Janio Szklaruk PhD, MD, Paul Silverman MD

CT angiography of an AVM – continuous infusion during scanning



Neurovascular Applications of CT Angiography
Prashant G Shetty, KS Jhaveri
Ind J Radiol Imag 2000; 10:

Impact of breathing-related motion on CT



AAPM TG76 report (Keall et al)

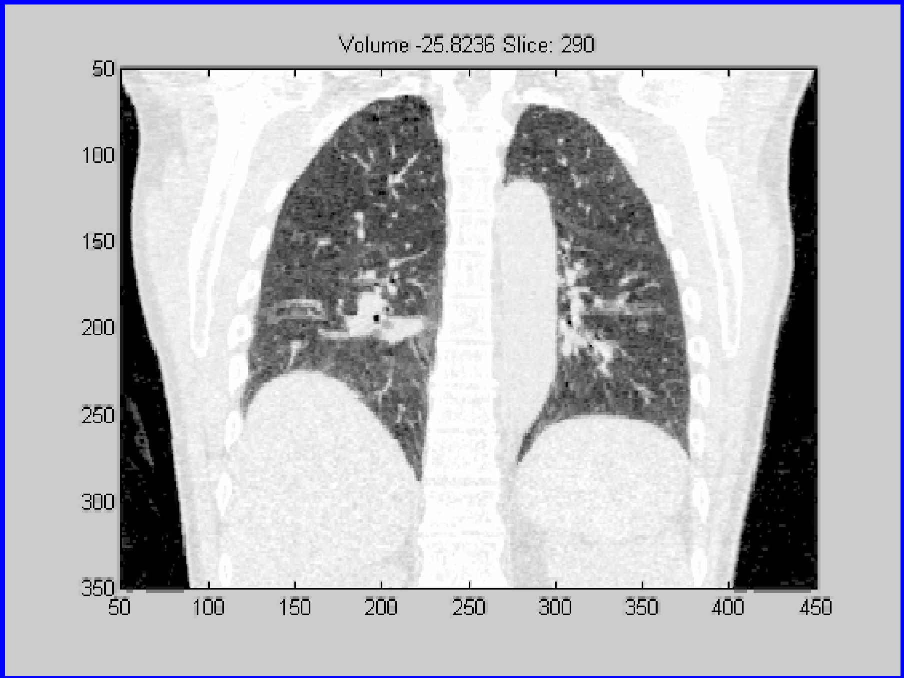
Modern Radiotherapy – the “4D” era?

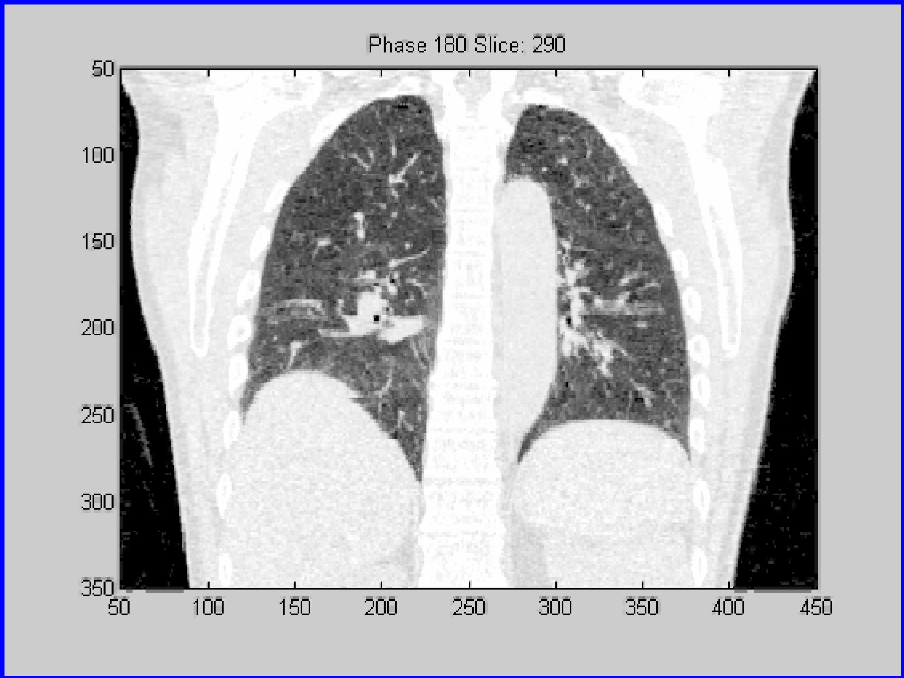
⚠ Warning:

Choking Hazard

Not for treatment planning systems over 3 years old!

4D CT: Coronal View



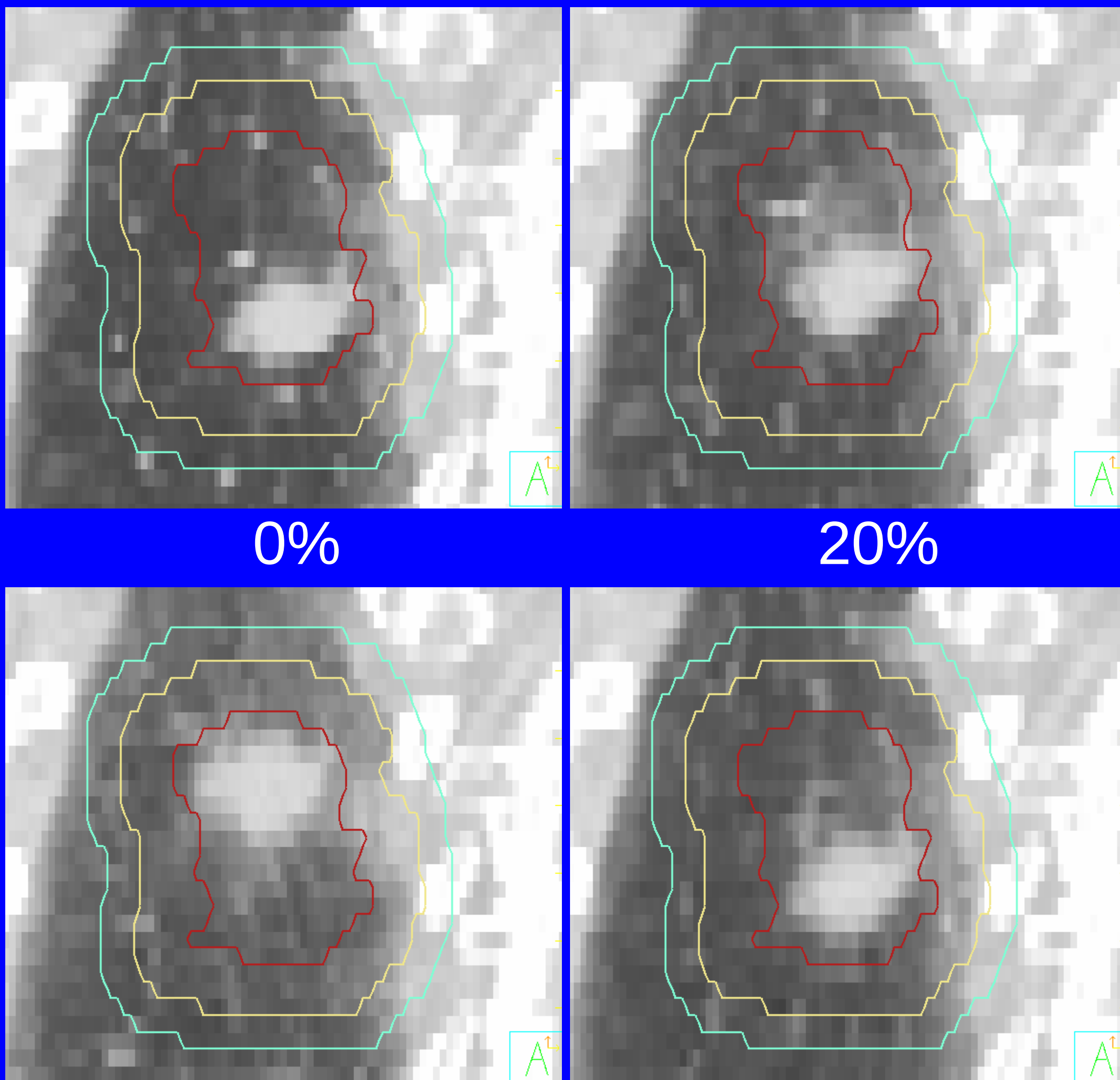


Amplitude sorting

Phase sorting

Dan Low, Washington University

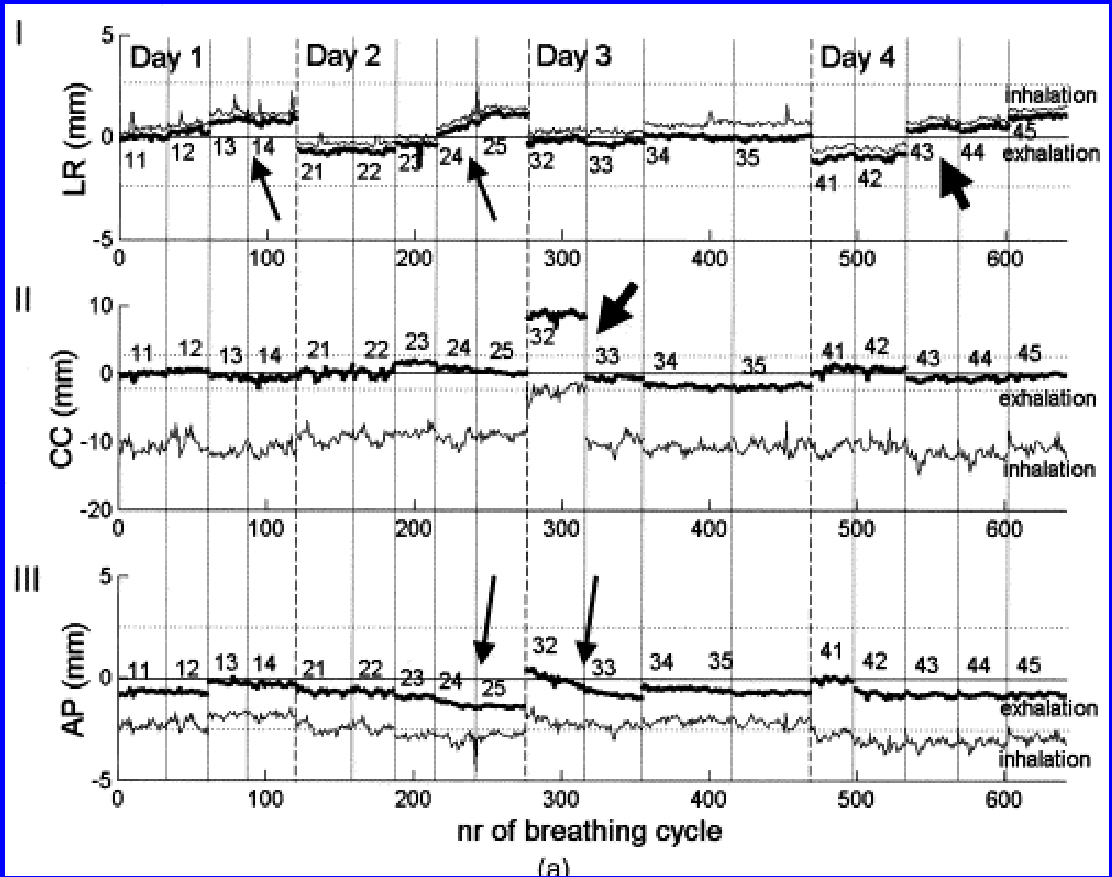
4DCT used to create an ITV


0%
20%
50%
70%
90%

Courtesy of Peter Balter, MDAC

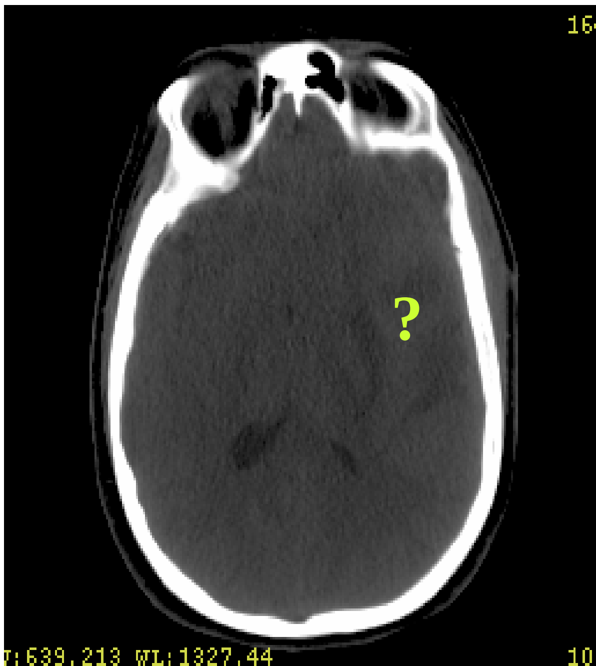
What happens when you don't look?

It is likely that models of the patient will need to include variations in estimated movement beyond those directly observed

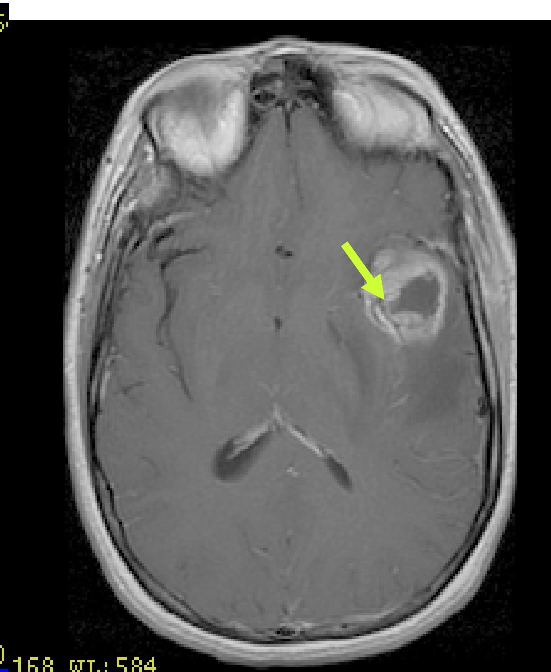


- Seppenwoolde et al IRJOB 53(4):822-33 (2002)

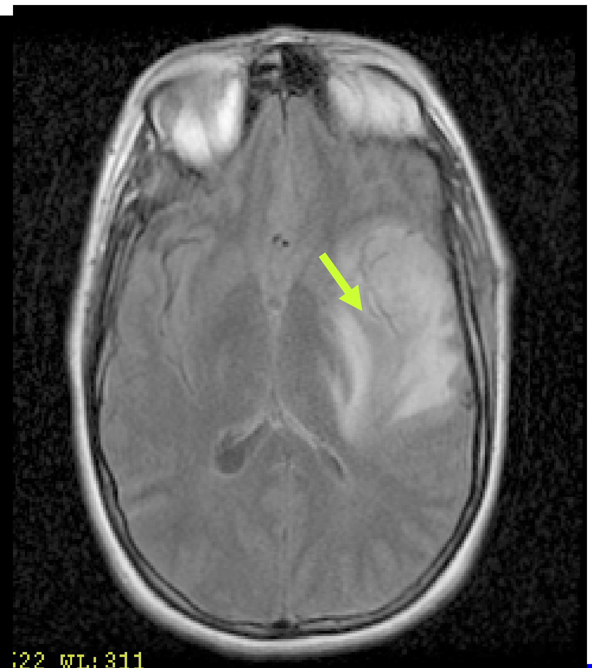
MRI aids in target delineation



CT



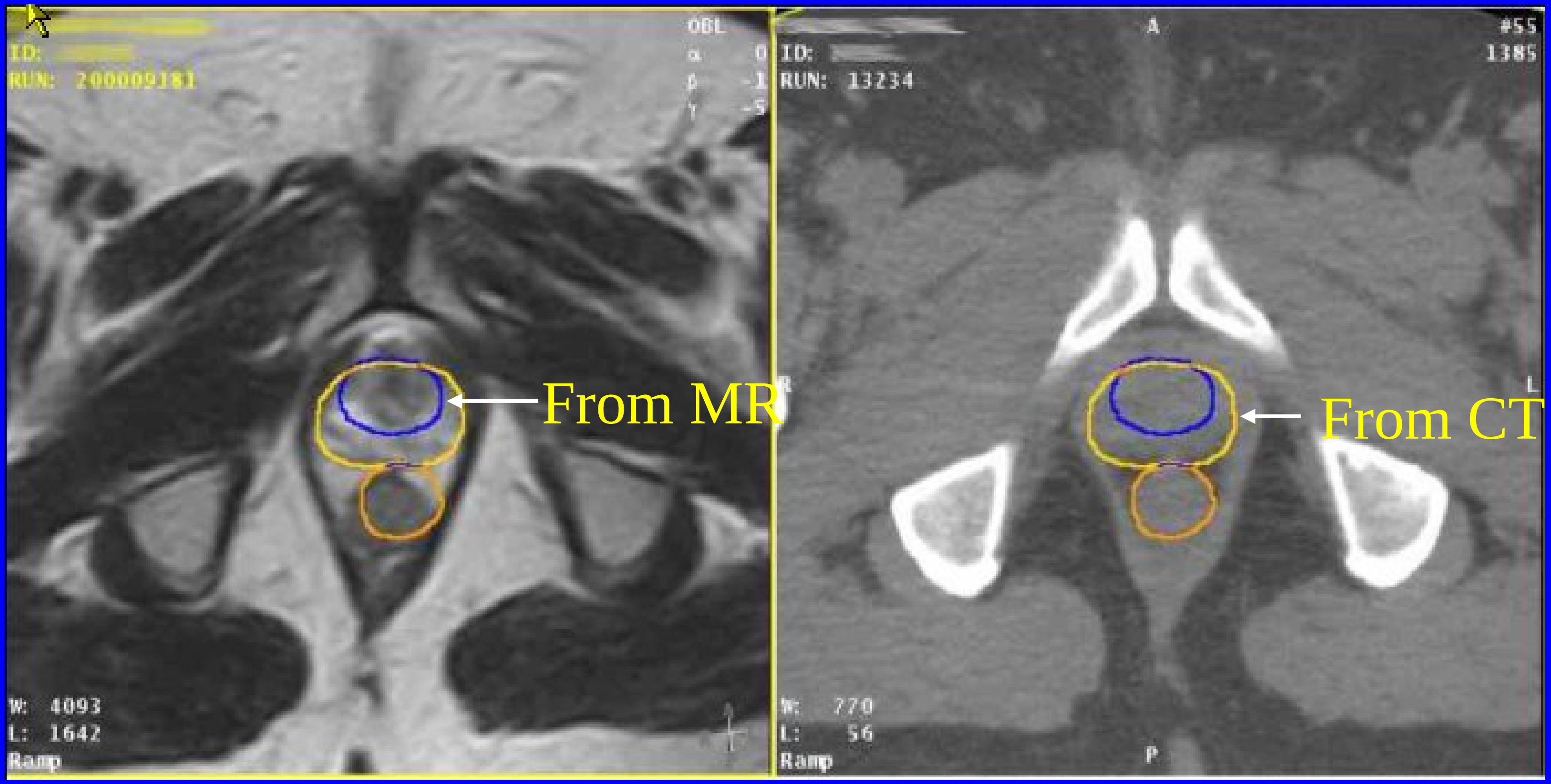
T1W



FLAIR

Y Cao, Universty fo Michigan

Prostate MRI (L Chen, Fox Chase Cancer Center)

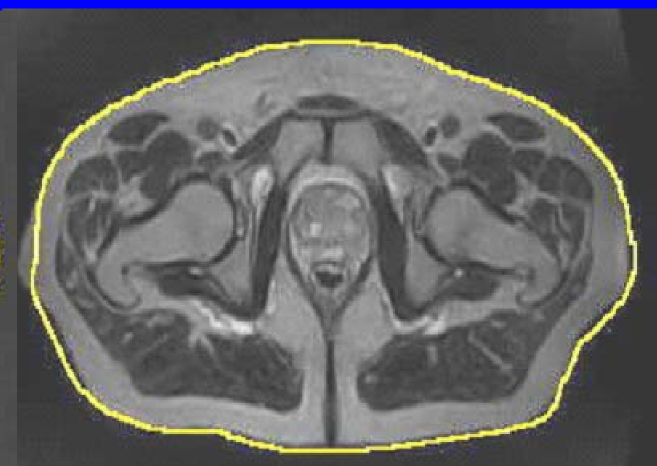


MR CT

Can distortion be handled effectively?

CT

Uncorrected MRI



GDC MRI

L Chen, FCCC

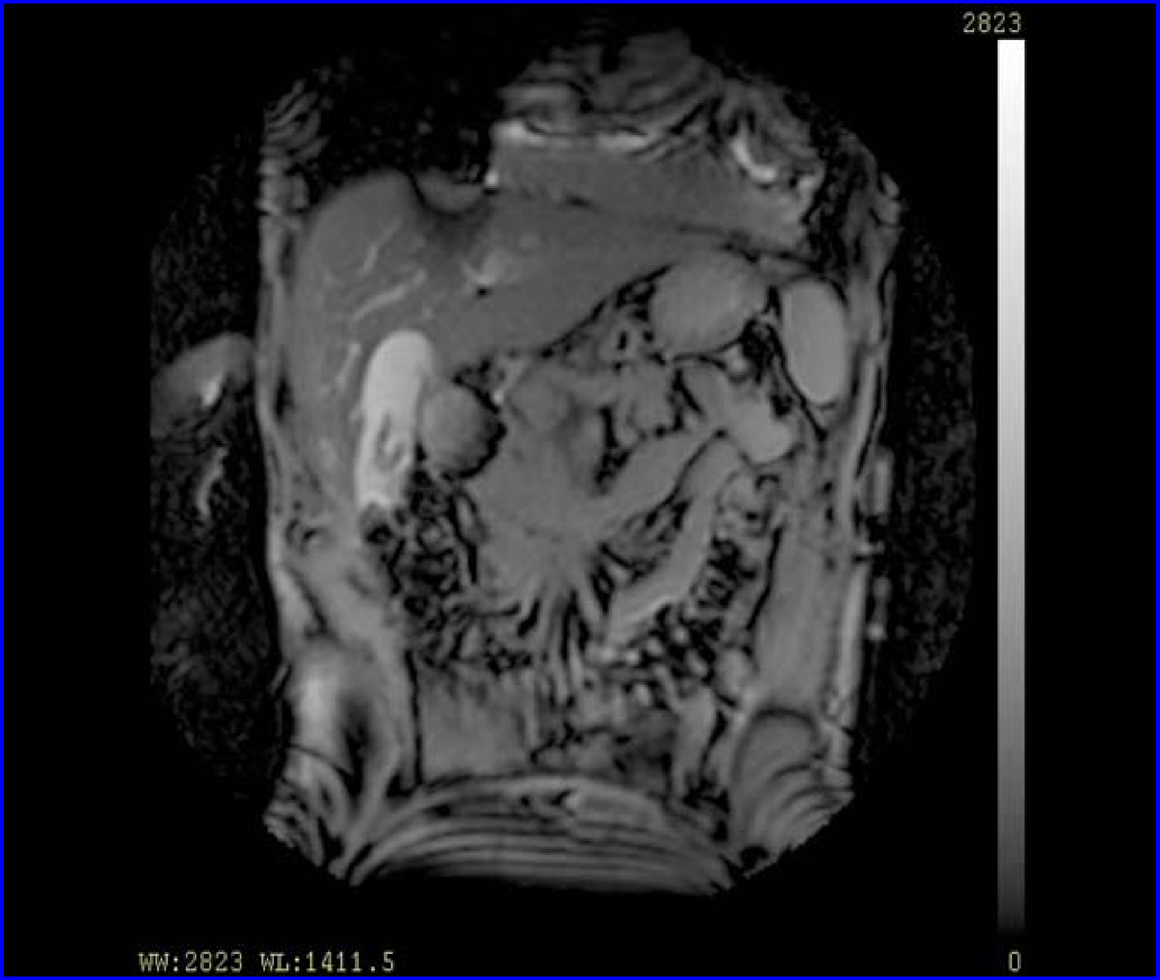
Who knows how to optimize imaging for target definition?

Research and development in imaging systems has focused heavily on sensitivity and specificity of DIAGNOSIS

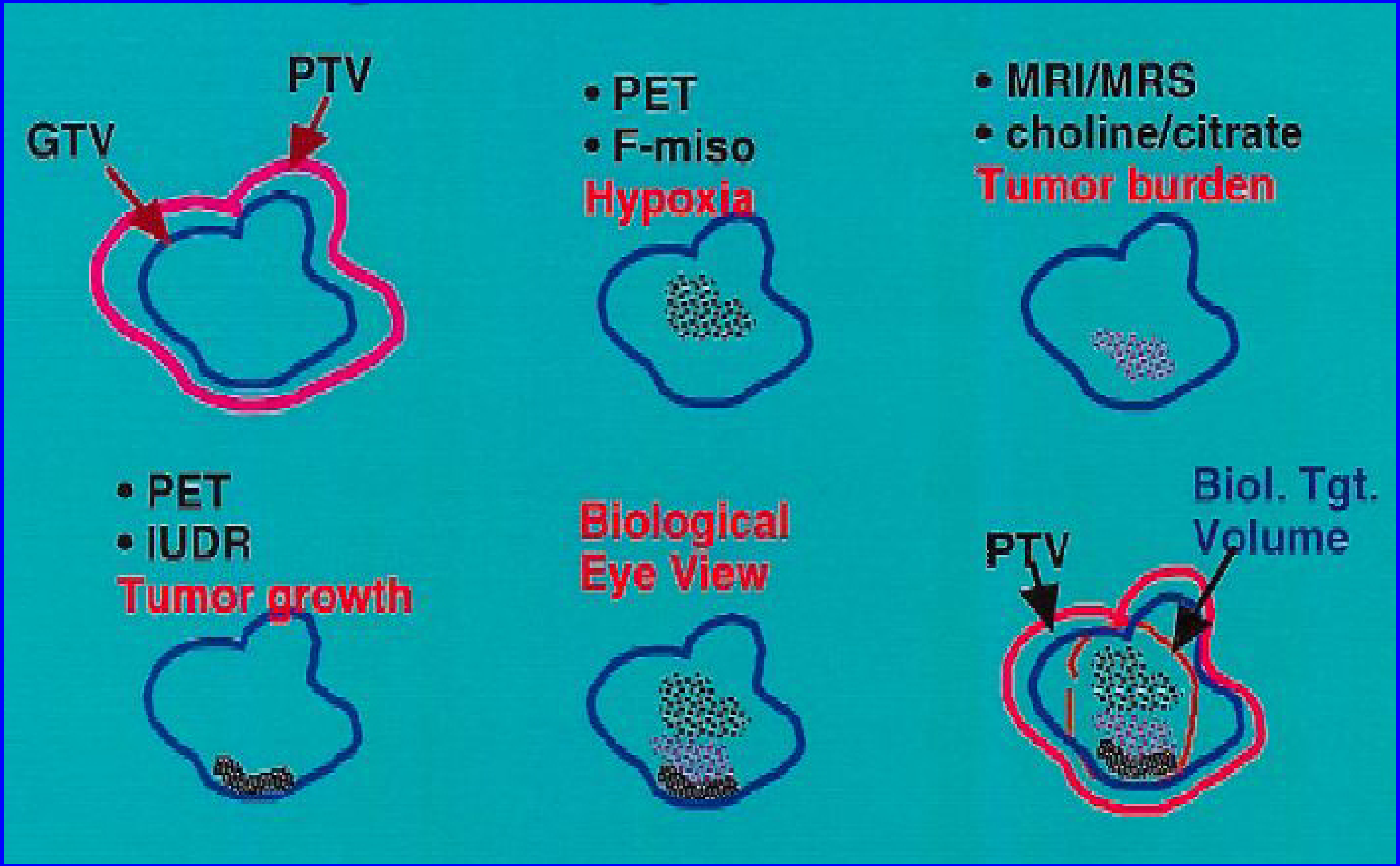
The concept of border delineation has not been a major area of R+D effort, and is a far more complex issue to resolve

Motion studies with MRI

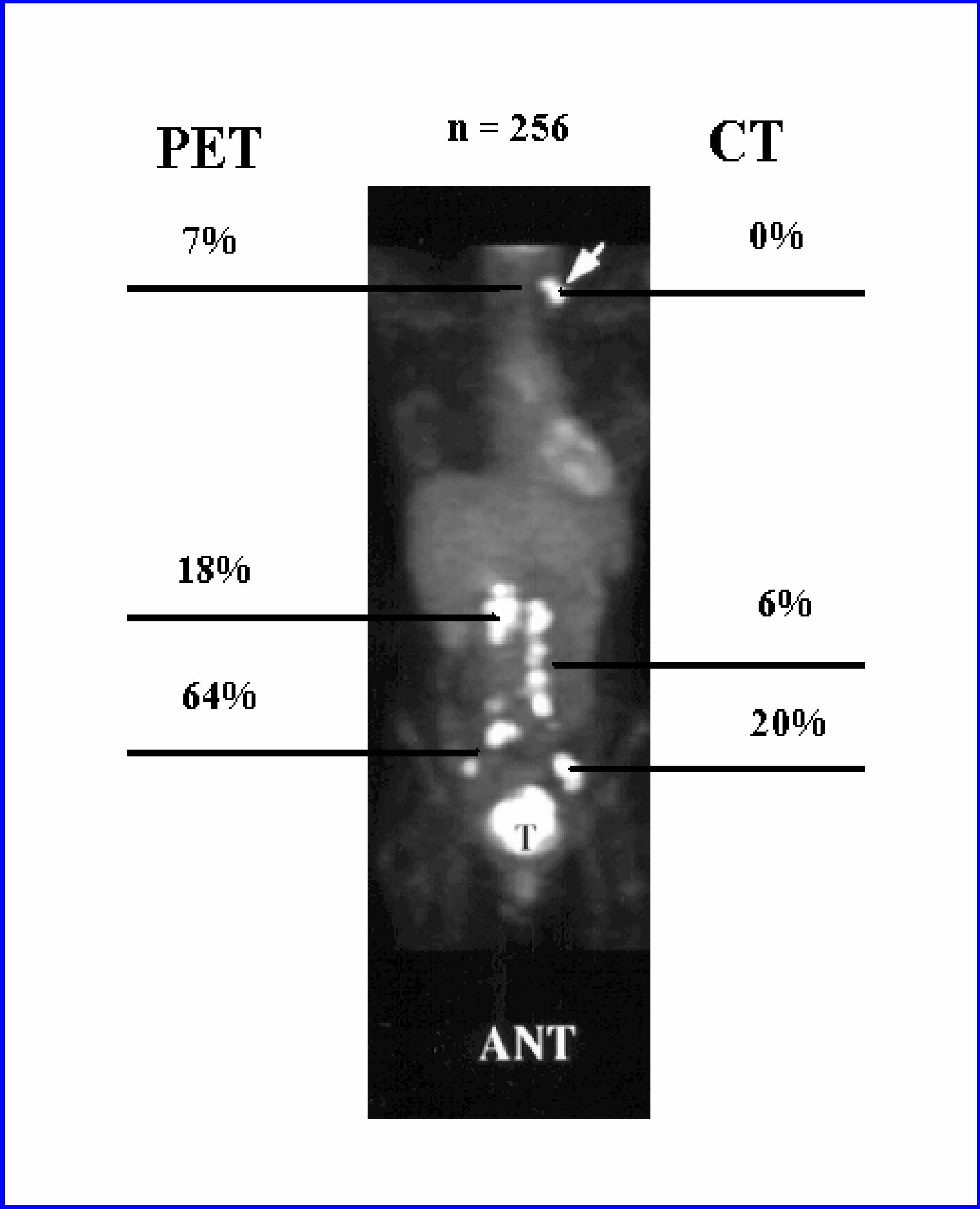
- Superior soft tissue contrast
- Not necessarily faster than CT
- Arbitrary planes
- Other tricks to improve speed



The potential of multimodality-imaging in RT



Ling et al IJROBP 47:551-560, (2000)



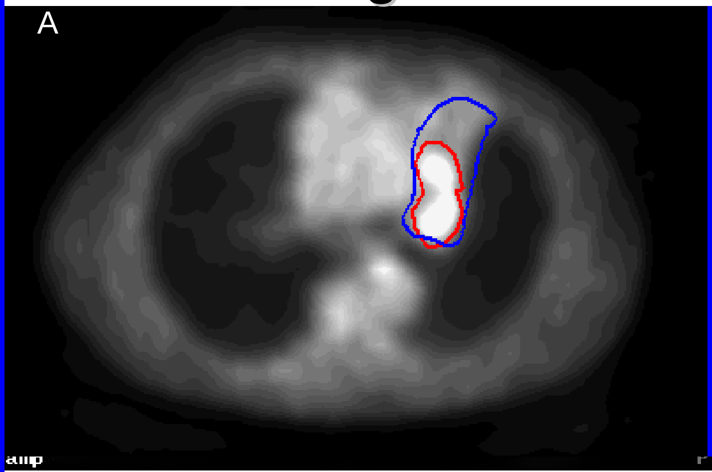
SITEMAN CANCER CENTER

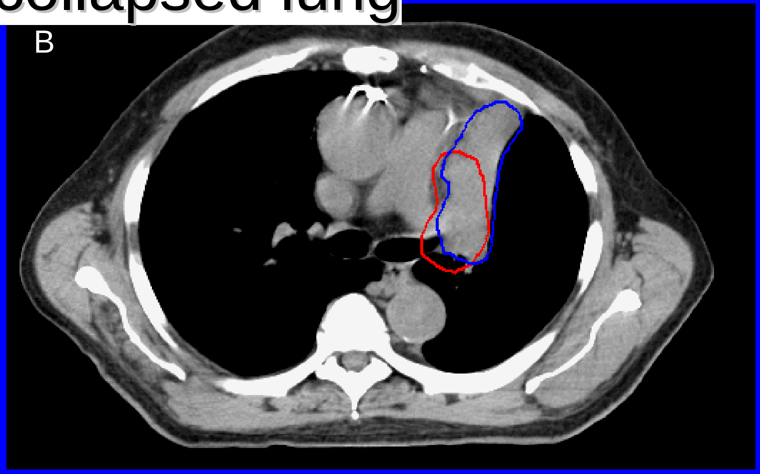
Courtesy of Sasa Mutic, Wash U

Grigsby et al, JCO, 2001

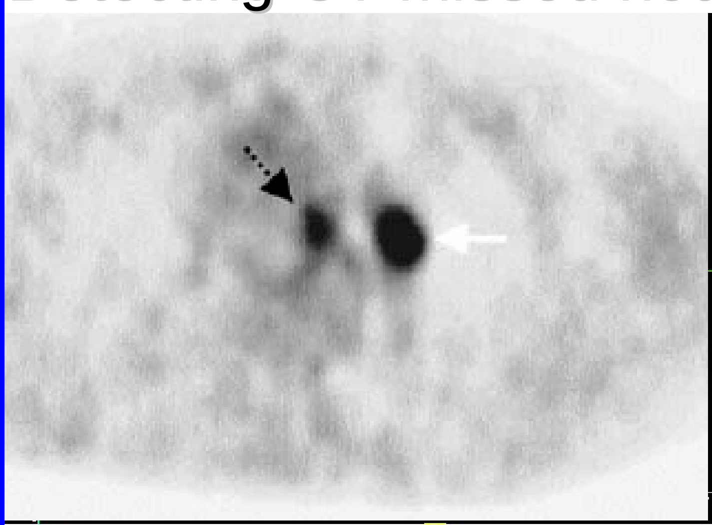
FDG-PET for target definition in the thorax (F Kong, University of Michigan)

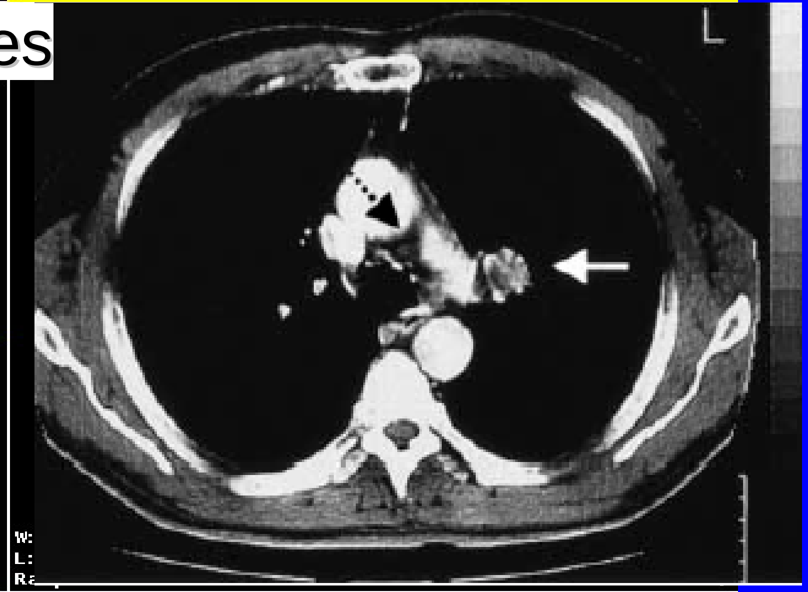
Differentiating tumor from collapsed lung





Detecting CT missed nodes

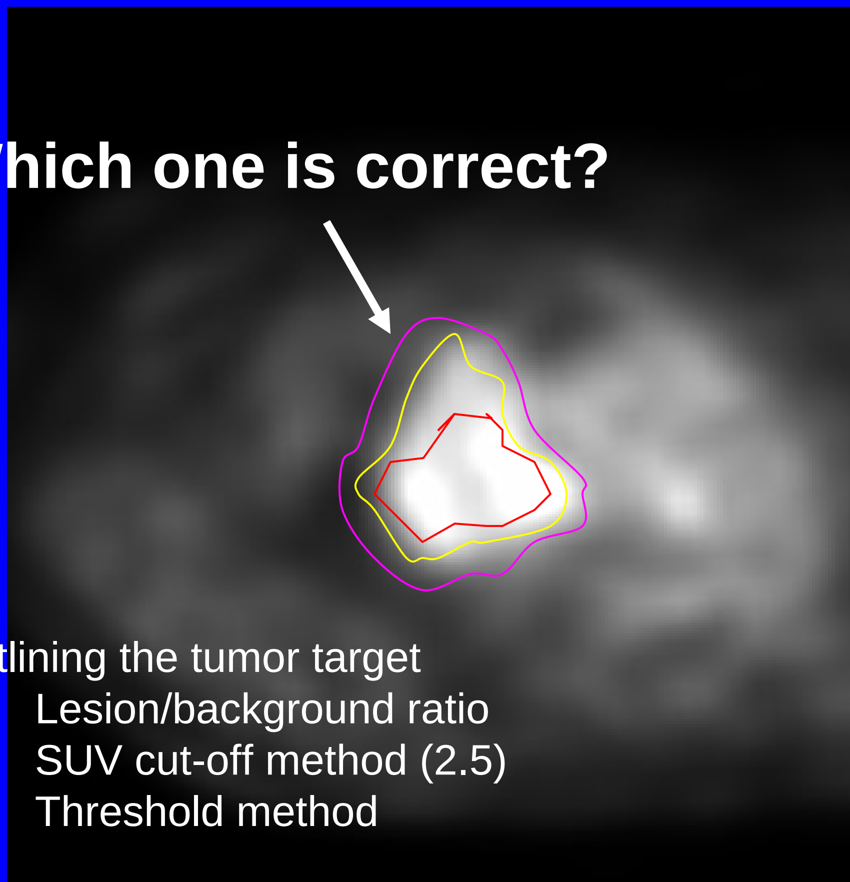




What is the tumor boundary from PET?

PET target compared to CT volume

Which one is correct?



Outlining the tumor target
- Lesion/background ratio
- SUV cut-off method (2.5)
- Threshold method

Threshold Method

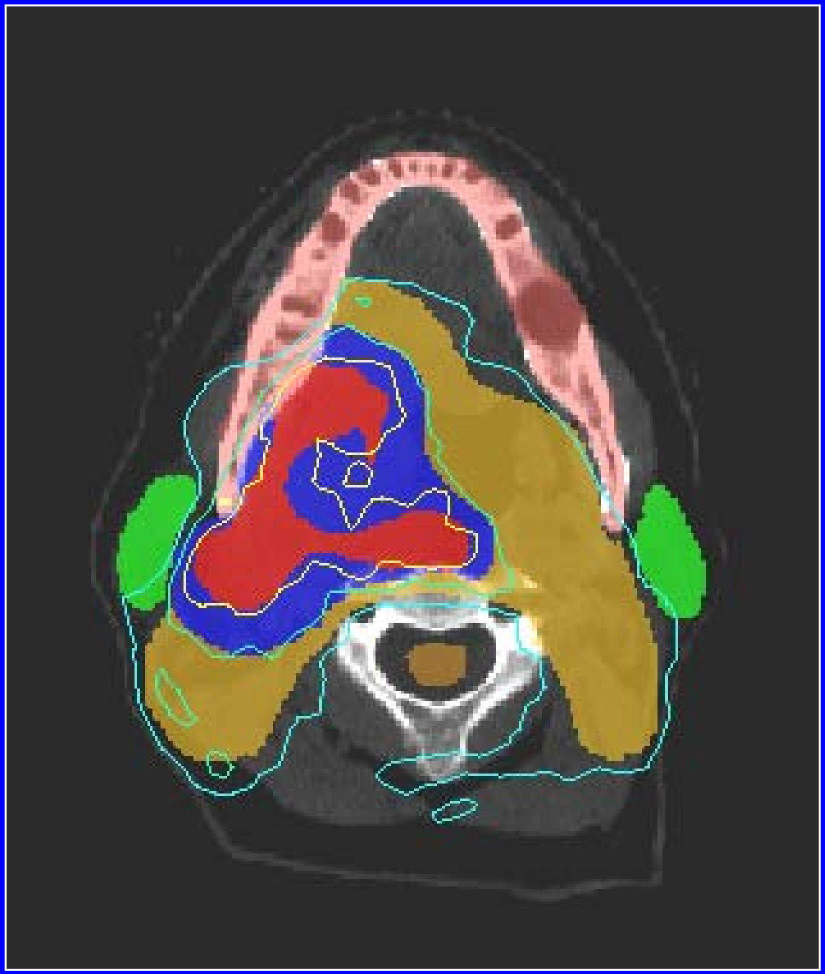
Study	Method of Delineation
Erdi et al, 1997 & 2002	**40% threshold**
Kiffer et al, 1998	**Visual interpretation**
Mah et al, 2002	**50% threshold**
Vanuytsel et al, 2000	**Identification only**
Nestle et al, 2005	**50% threshold**
Bradley et al, 2004	**40% threshold**
Deniaud-Alexandre et al, 2005	**50% threshold**
Giraud et al, 2001	**40% threshold**
Brianzoni et al, 2001	**40% threshold**
Ashamalla et al, 2005	**Visual interpretation**

F Kong, U of Michigan

Altered/Escalated Dose Distributions

^{60}Cu-ATSM (Hypoxia) - Guided IMRT

Mutic et al, Washington University



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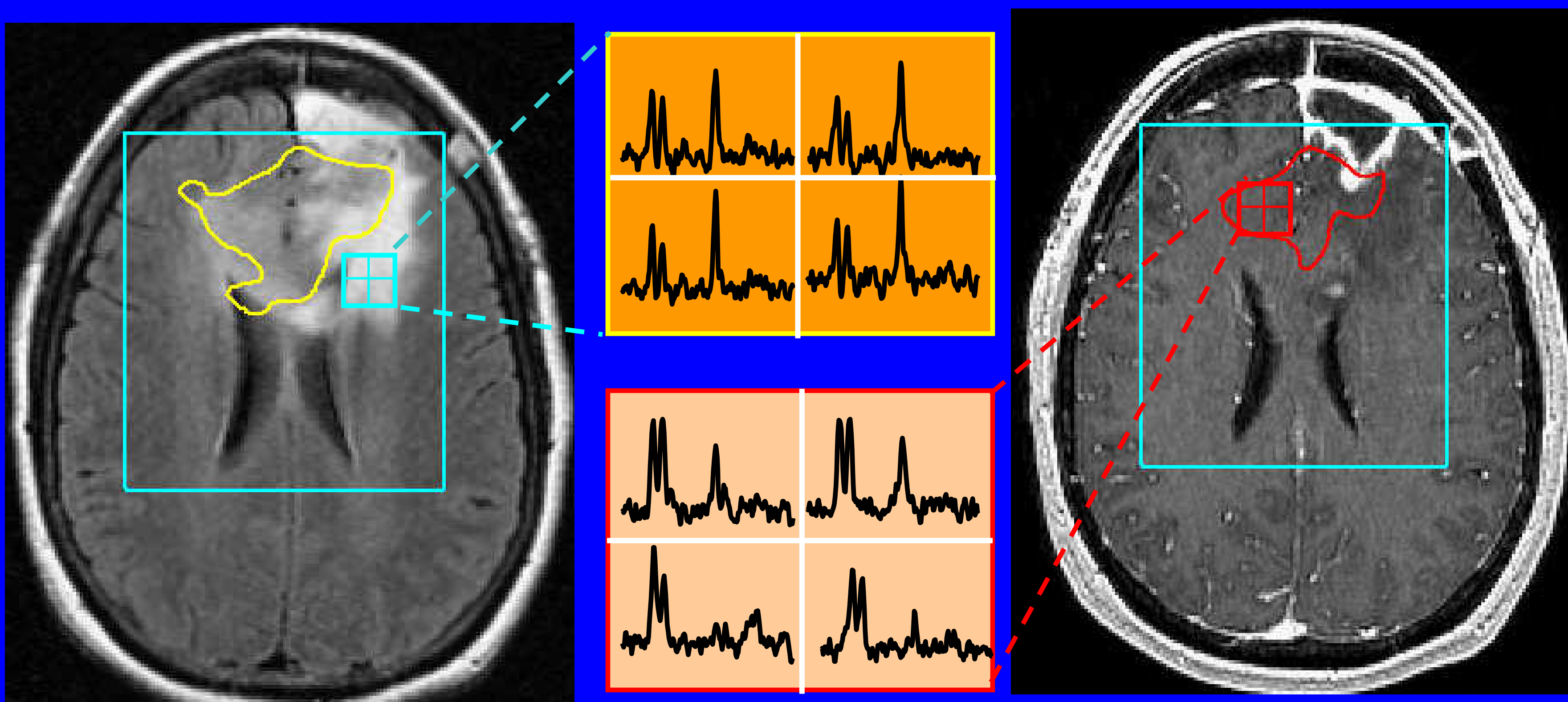
BARNES-JEWISH HOSPITAL • WASHINGTON UNIVERSITY SCHOOL OF MEDICINE

Chao *et al.* IJROBP 49:1171-1182, (2001).

Incorporation of MRSI data into Treatment Planning for RT of a GBM



T2 hyperintensity outside CNI 2

CNI3 outside CE

UCSF

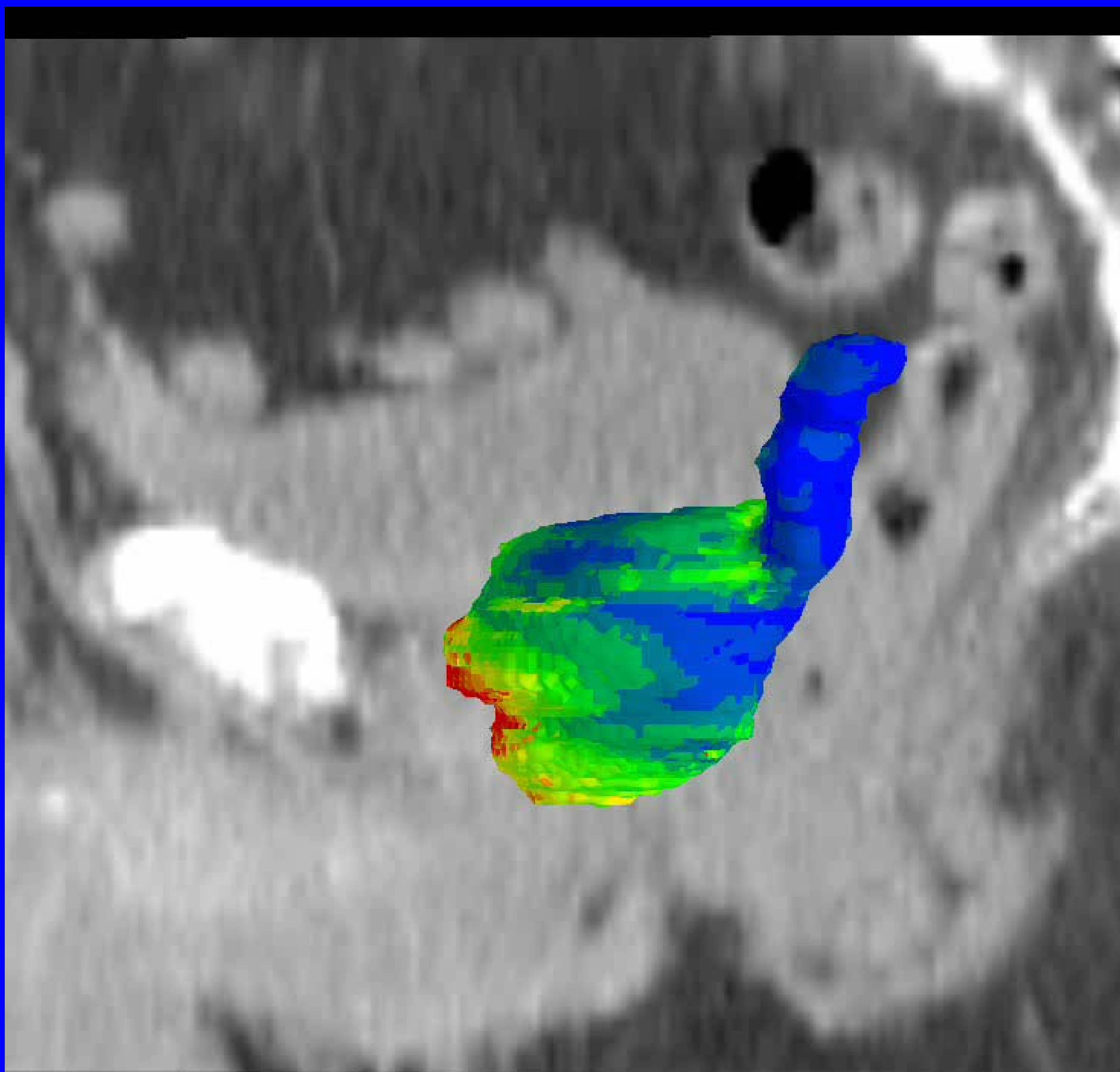
A Pirzkall, UCSF

Contouring

For the SAME contrast and image information, target delineation may significantly vary between experts

This target definition variability is a critical source of uncertainty in Radiation Oncology today

3-D median surface with local SD Van Herk et al (NKI)



LOCAL SD (mm)

0.0 – 0.5
0.5 – 1.0
1.0 – 1.5
1.5 – 2.0
2.0 – 2.5
2.5 – 3.0
3.0 – 3.5
3.5 – 4.0
4.0 – 4.5
4.5 – 5.0
5.0 – 5.5
5.5 – 6.0
6.0 – 6.5
6.5 – 7.0
7.0 – 7.5
> 7.5

Imaging for treatment verification

1980's – port films

1990's -	emergence of MV portal imagers
	in-room ultrasound localization
	marker-based localization
	Fluoroscopic tracking
2000's –	flat panel imaging
	KV digital imaging
	CBCT
	MV CBCT
	CT "on rails"
Emerging -	Electromagnetic localization and tracking
	surface tracking
	in-room MRI

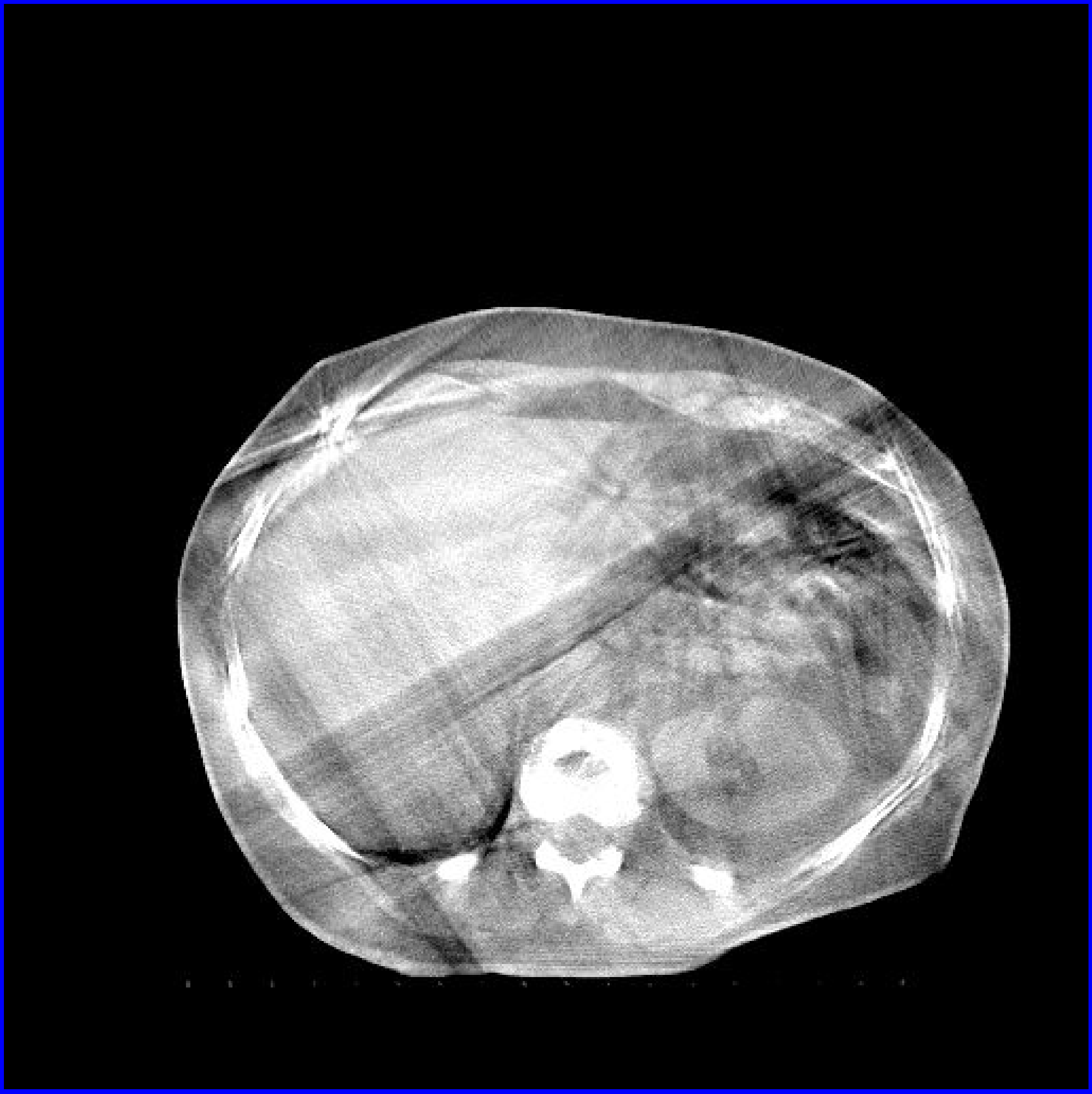
Considerations of appropriate use of in-room imaging

Localization – As surrogate anatomy approaches the true target through improved visualization, uncertainty reduces in tumor location

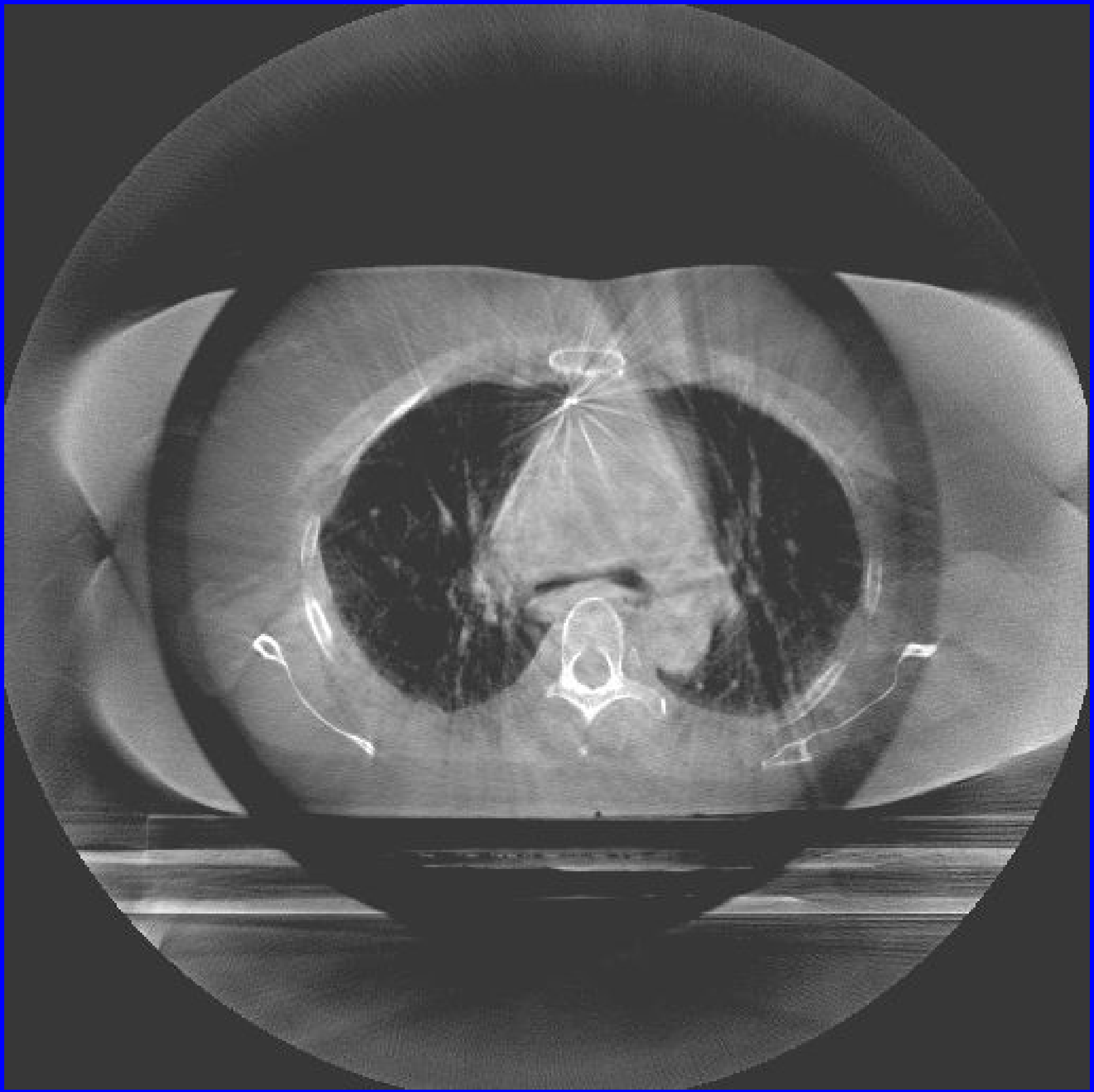
Caveat – Improved direct tumor visualization is currently not amenable to real-time localization and action, thus:

- surrogates are more likely to be needed for rapid monitoring for the moment
- sampling the patient in the treatment room still requires a tie to immobilization and residual uncertainty analysis

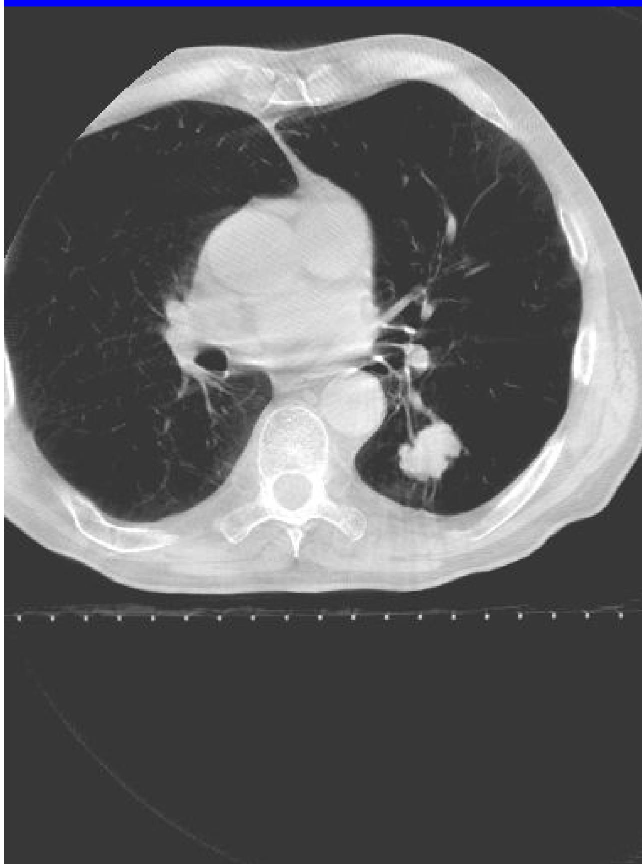
CBCT – the ugly…

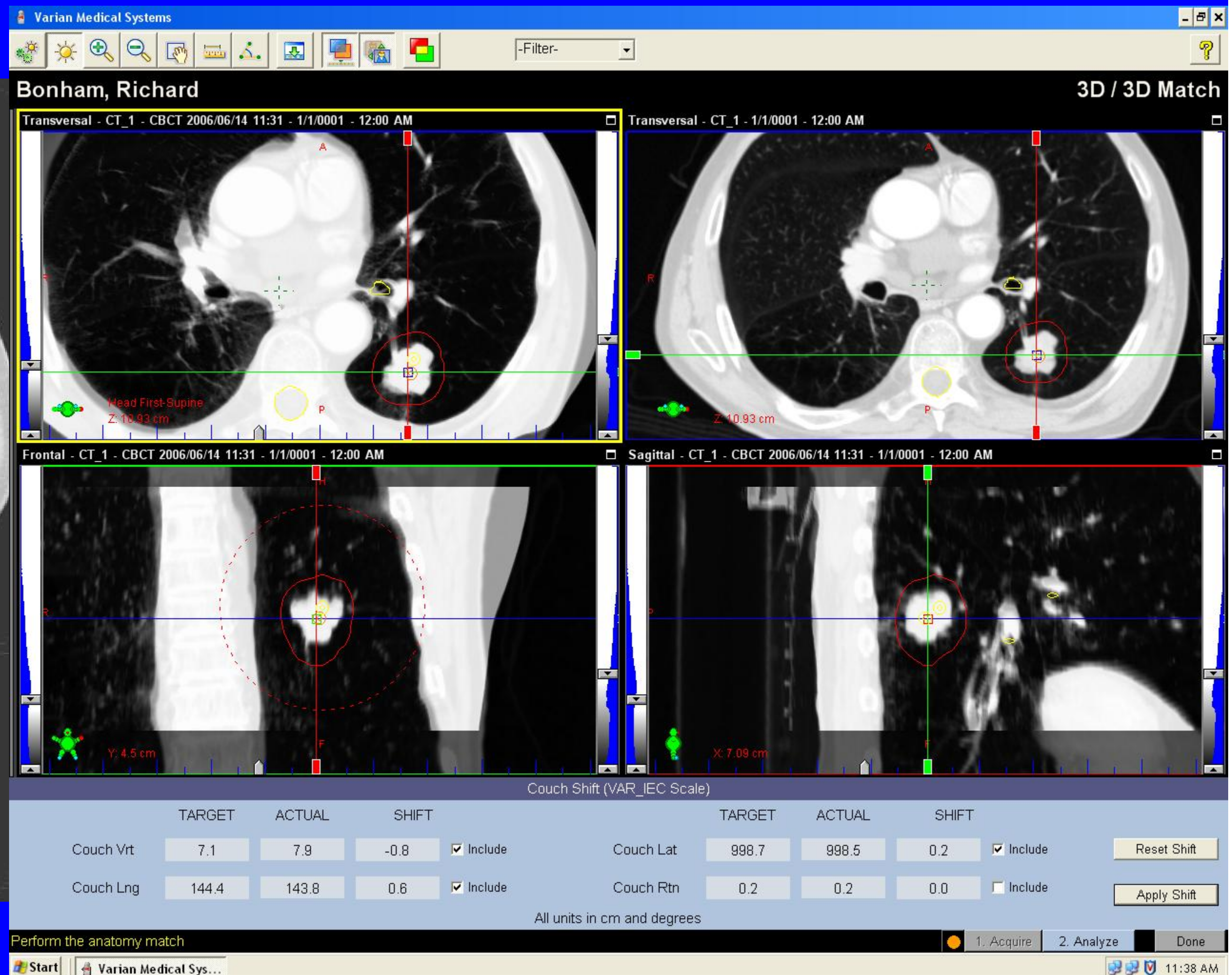


CBCT – the bad…



CBCT – the good…





Proper use of imaging requires infrastructure, skill sets, and role consideration

- Understanding limits and optimal use of imaging systems
- Proper QA procedures (relationships of image quality to functional use)
- Understanding and routine use of alignment tools
- Data management – Who uses what data where, when, and how, and how much infrastructure is needed to support use?
- “targeting” moving into the hands of a larger population of users with variable training
- Potential for plan modification – benefit not fully defined, heavy reliance on relationships between sampled data sets and understanding of what may be true but not sampled
- Use of rule-based strategies for intervention – acceptance of statistical models over the last image seen

…

Dealing with Imaging in Radiation Therapy – AAPM efforts

This Summer school

Scientific Program Committee – Joint topics and sessions

Educational program at AAPM

Science council:

- Therapy physics committee
  - Therapy Imaging Subcommittee
    - WG on imaging for treatment planning
    - WG on umaging for treatment verification
    - WG on imaging for treatment assessment
    - WG on molecular imaging in clinical radiation oncology

Major topics of the IGRT section of this workshop:

- Imaging for treatment planning
  - Concerns in optimizing imaging and contouring
  - Imaging technology (CT, PET, MRI)
  - Related tools (image alignment)
- Imaging for treatment verification
  - Technology (Radiograph, ultrasound, (CB)CT)
  - Tools (Alignment, tracking)
  - Decision support (adaptive methods)
  - Support issues (QA, commissioning, safety, infrastructure)
- YOUR QUESTIONS AND DISCUSSIONS ARE THE MOST IMPORTANT COMPONENT OF LEARNING!

Administrative notes – Badge number for CME

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1	2	2	2
2	3	3	3
3	4	4	4
4	5	5	5
5	6	6	6
6	7	7	7
7	8	8	8
8	9	9	9
9	0	0	0

Administrative notes

Due to a scheduling conflict, the Imaging for patient modeling talks on PET and MRI will be held today at 1:30-3:30, and the CT talks will be held tomorrow from 8:00-10:00. The schedule is correct in the handout, but the CME reviews are not. Please fill out the appropriate box for review. Thank you!