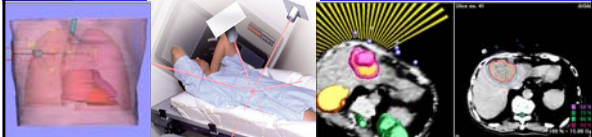


# Establishing SBRT Program: Physics & Dosimetry

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## Outlines

- ❑ Illustrate the difference between SBRT vs. CRT
- ❑ Introduce the major procedures in SBRT:
  - Simulation while assessing target motion;
  - Target definition: how to account for motion;
  - Treatment planning consideration;
  - Treatment delivery with imaging guidance.
- ❑ Present physics and dosimetry issues involved.

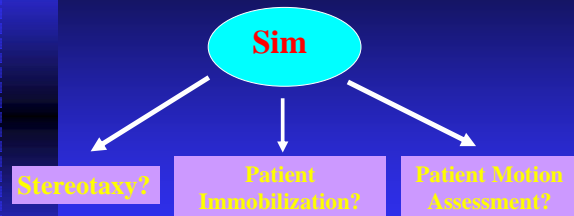
### SBRT



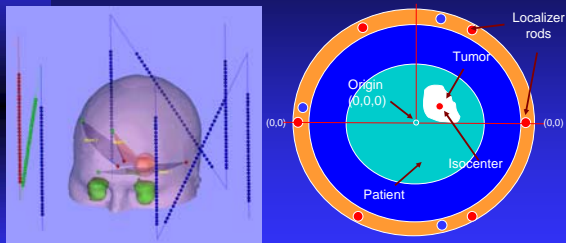
### CRT



### SBRT - Simulation

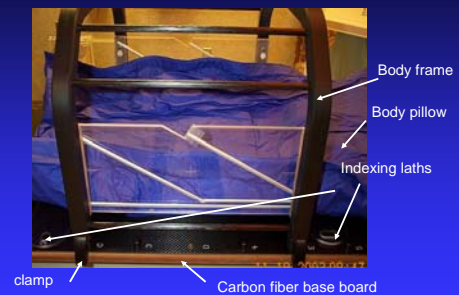


### Stereotaxy



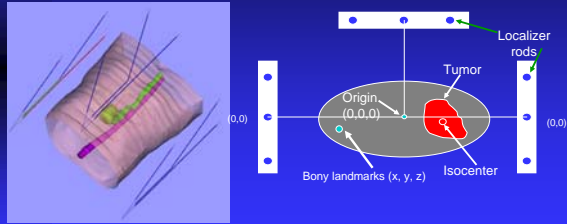
Stereotaxy refers to a 3D superposition of a fixed coordinate system upon a given organ.

### Body Localizer

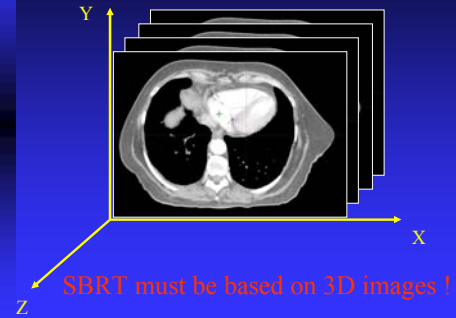


SBL provides a rigid reference for patient setup and re-alignment, as well as assists image fusion.

## Stereotaxy in Extracranial Sites



## 3D Images Provide Stereotaxy



## Conventional vs SBRT

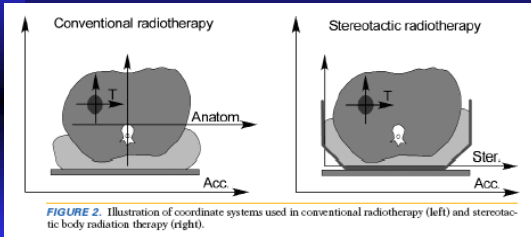


FIGURE 2. Illustration of coordinate systems used in conventional radiotherapy (left) and stereotactic body radiation therapy (right).

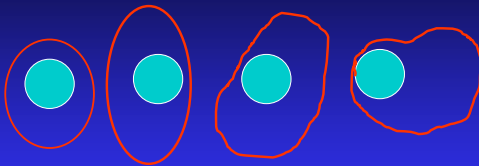
\* Slide courtesy of Brian Kavanagh / University of Colorado

## Patient Immobilization



➤ SBRT simulation begins with patient-specific mold making and immobilization of patient.

## Motion Assessment



SBRT requires a determination of patient-specific internal target volume (ITV)

What imaging procedures to use in order to determine the ITV?

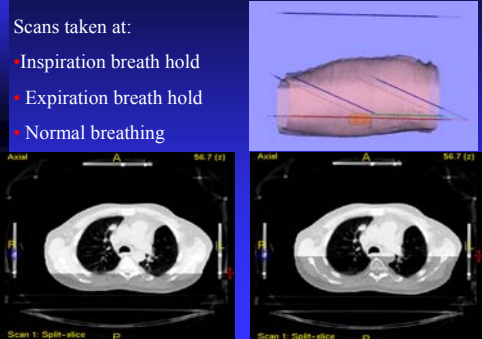
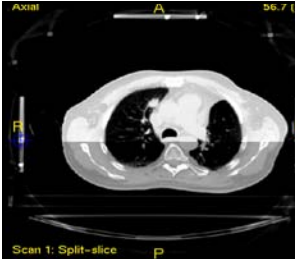
## 4DCT Simulation



## Multiphase CT Scans & Image Fusion

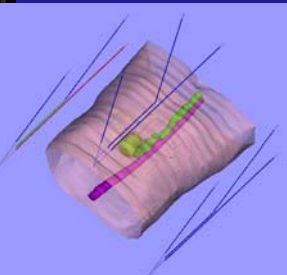
Scans taken at:

- Inspiration breath hold
- Expiration breath hold
- Normal breathing

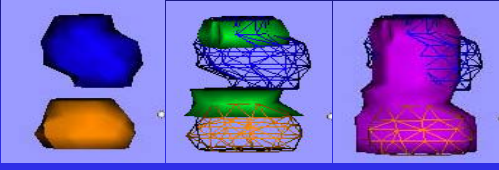



Frame registration helps to contrast the tumor motion

Establish stereotaxy for target localization

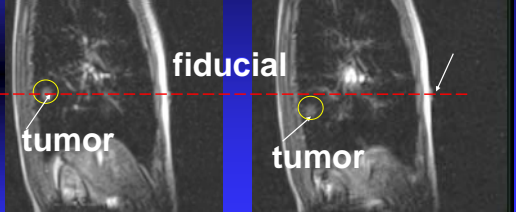


## Composite Target or ITV



Three targets from normal breathing, inspiration and expiration breath hold scans. Due to motion artifact, the target on the normal breathing appears to have two separate targets (green).

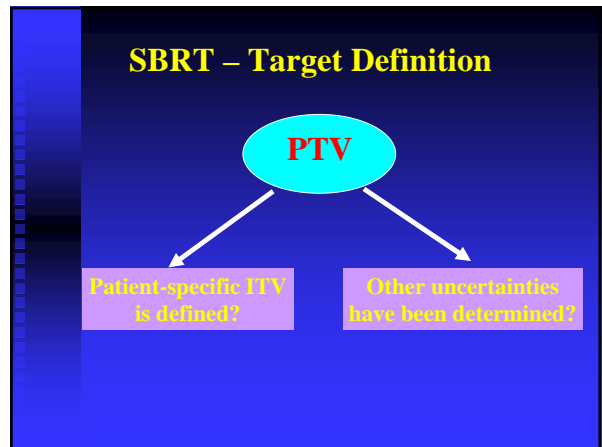
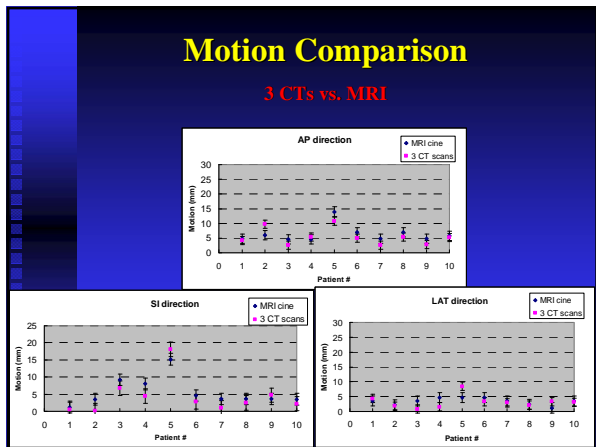
## Motion Study with MRI Cine



fiducial

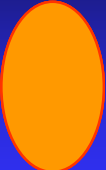
tumor

tumor

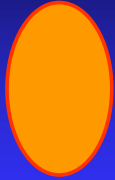


## ITV Definition

**4D MIP Approach:**



**3 Multiphase CT Approach:**



Inspiration  
Normal breathing  
expiration

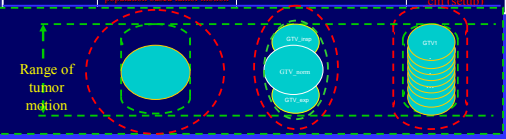
Patient specific ITV

## Other Uncertainties

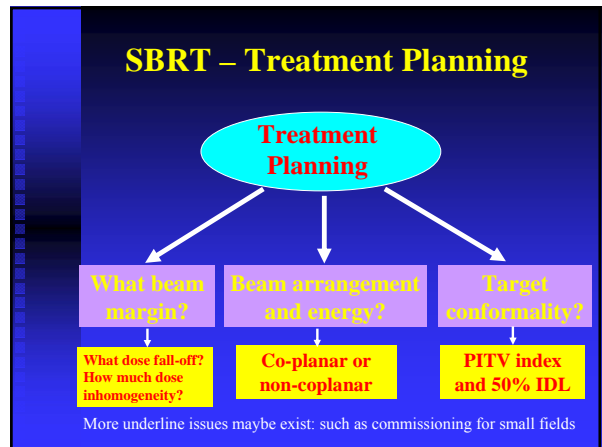
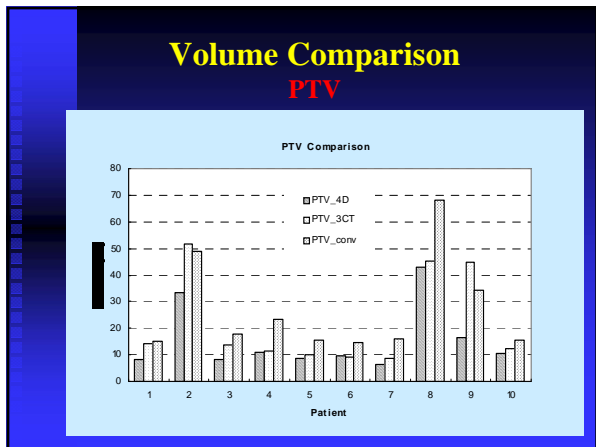
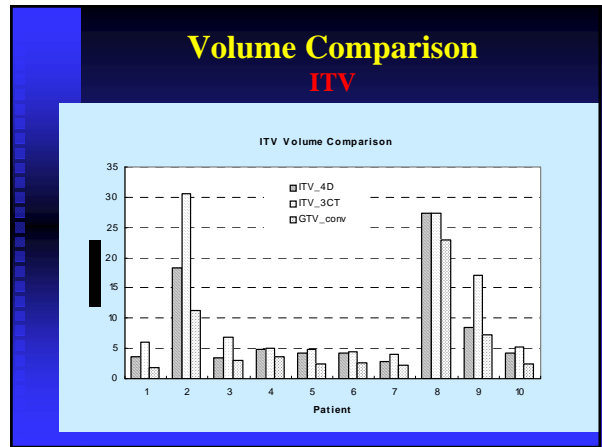
- Whether using 3D imaging guidance?
  - If yes, how much uncertainty is associated with the imaging system?
- Can setup error completely be corrected by imaging guidance?
  - If not, what is the residual error (image resolutions, ...etc)?

## Comparison of Target Definitions

Parameter	3D standard	3 Multiphase CT	4D Union
Planning CT scan	Free-breathing slice-based	Max. inspiration and expiration breath holding + free-breathing CTs	4D CT (or MIP)
GTV or ITV	Standard GTV	GTV_free U GTV_insp U GTV_exp	GTV1 U GTV2 U ... U GTVn
CTV	GTV+0.0 cm	ITV+0.0 cm	ITV+0.0 (or 0.5) cm
PTV	CTV+0.5 (cm) setup + population based tumor motion	CTV+0.3-0.5cm (setup)	CTV+0.3-0.5 cm (setup)



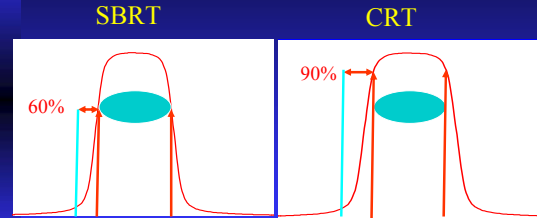
Range of tumor motion



## Typical Margins Used

- ❖ Various margins were reported: from 0 – 1.0 cm
- ❖ It depends on the dose inhomogeneity desired.
- ❖ It also depends on the machine to be used for treatment planning – such as Cyberknife - may use multiple isocenters – thus, the dose inhomogeneity is high.

## Dose Fall-Off



## MC Investigation of Block Margin

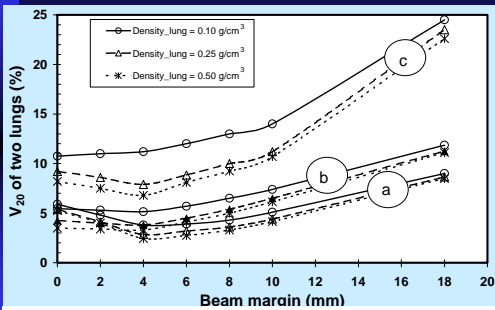
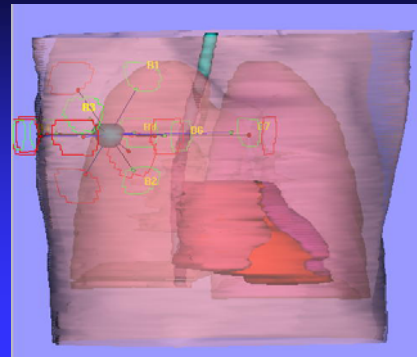
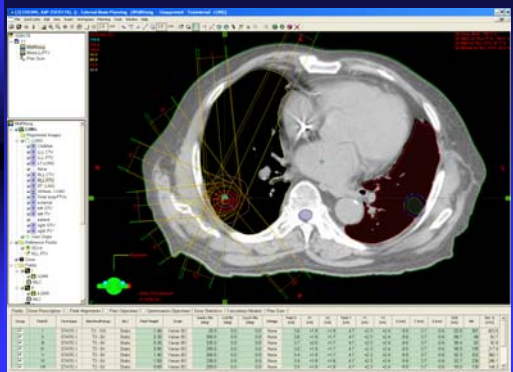


Figure 4.  $V_{20}$  versus the beam margin for three lung densities and three PTV sizes: (a) 14.4 cm<sup>3</sup>, (b) 22.1 cm<sup>3</sup> and (c) 55.3 cm<sup>3</sup>, respectively.

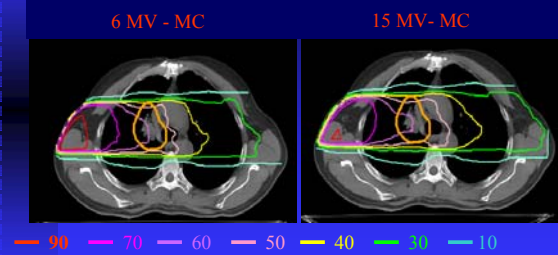
## Non-coplanar Beam Arrangement



## Coplanar Beam Arrangement

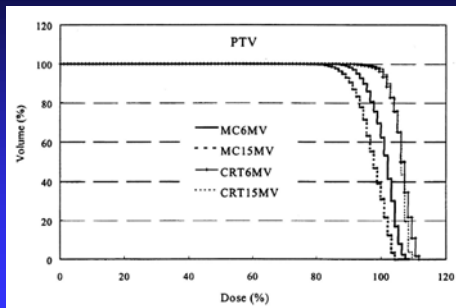


## Energy Effect in Patient



Wang et al. Appl. Clin. Med. Phys. (2002)

## Energy Effect in Patient



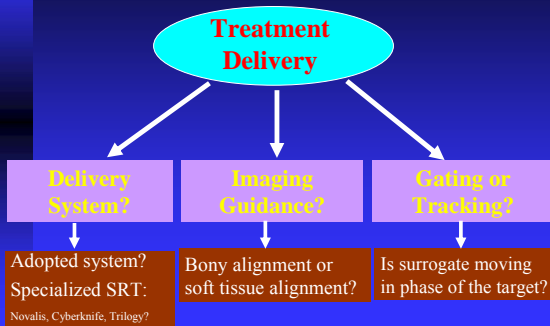
Wang et al. J. Appl. Clin. Med. Phys. (2002)

## Target Conformality

Different protocol has different specifications. E.g. RTOG 0915 Requires:

- PTV is close to unit as much as possible (1.2 – 1.5)
- 50% line also should follow the shape of the target – the distance from the prescribed IDL to the 50% IDL < 2.0 cm
- The prescription isodose surface must be  $\geq 60\%$  and < 90% of the maximum dose (normalized to the maximum dose point).
- High dose spillage requirements: - the cumulative volume of all tissue outside the PTV receiving a dose >105% of the prescription dose should be no more than 15% of the PTV volume.

## SBRT – Treatment Delivery



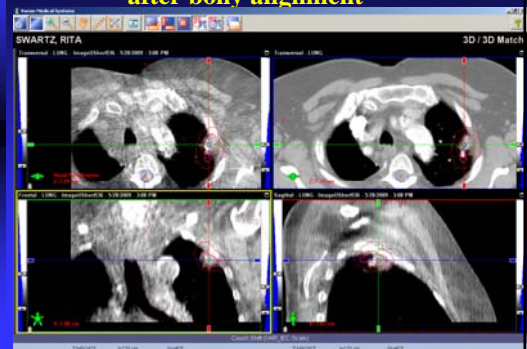
## Linear Accelerators with features especially suitable for SBRT



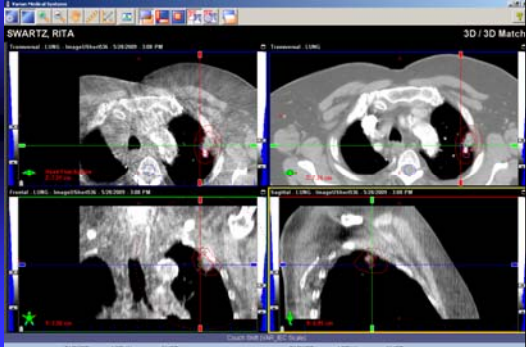
## On Board Imaging – Cone Beam



## Cone Beam CT Guidance after bony alignment



## Cone Beam CT Guidance after soft tissue alignment



## Image Guidance using CT-on-Rails



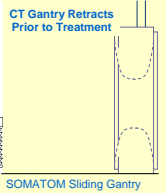
Siemens PRIMART in a treatment room

## Treatment Setup



Treatment setup based on a stereotactic box to establish the rigid relationship with the machine reference.

Zero the table coordinate



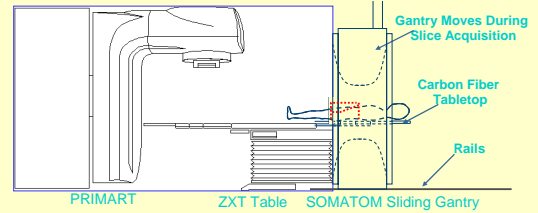
PRIMART

ZXT

SOMATOM Sliding Gantry

## Image Guidance using CT-on-Rails

### 3-D Target Localization with a SOMATOM CT



PRIMART

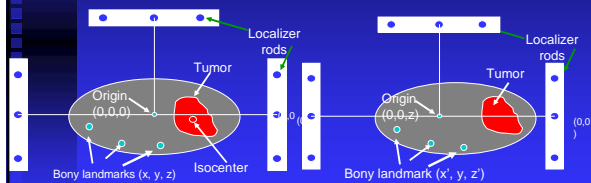
ZXT Table

SOMATOM Sliding Gantry

## Daily Target Localization: Bony Landmarks Shifts

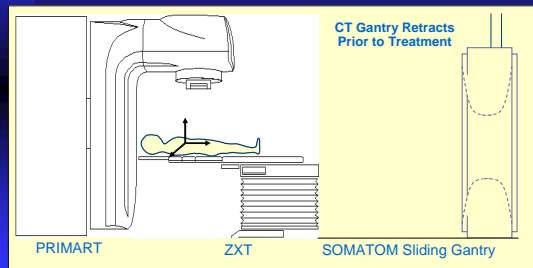
Coordinates from SIM CT

New coordinates from Treatment CT



$$\Delta X = X' - X, \Delta Y = Y' - Y, \Delta Z = Z' - Z$$

## Patient Relocalization for Treatment



PRIMART

ZXT

SOMATOM Sliding Gantry

Shift the table if necessary

## Physics & Dosimetry Issues

- ❖ Small field dosimetry - beam commissioning for small fields (output factor, profile...etc.)
- ❖ Quality assurance of imaging guidance system – known the accuracy and limitations
- ❖ Using IMRT vs. conformal approach – is there any benefit in using IMRT and when to use it?

## Summary: SBRT Requirements

- Higher confidence in tumor targeting and appropriate accounting of internal organ movement.
- Reliable mechanisms for generating focused, sharply delineated dose distributions
- Reliable accurate patient positioning accounting for target motion related to time dependent organ movement

## SUMMARY: SBRT Physics and Technology

- ❖ **CT simulation:** Need assess tumor motion
- ❖ **Immobilization:** Minimize motion, breathing effects
- ❖ **Planning:** Small field dosimetry considerations
- ❖ **Repositioning:** High precision patient set-up.
- ❖ **Relocalization:** Identify tumor location in the treatment field:
  - \* MV/ kV x-ray, implanted markers and/or set-up fiducials
  - \* Motion tracking and gating systems
  - \* Real-time tumor tracking systems with implanted markers
- ❖ **Treatment delivery techniques**
  - \* Adapted conventional systems
  - \* Specialized SRT: Novalis, CyberKnife, Trilogy...

