Physics and Dosimetry of SBRT: Simulation and Localization

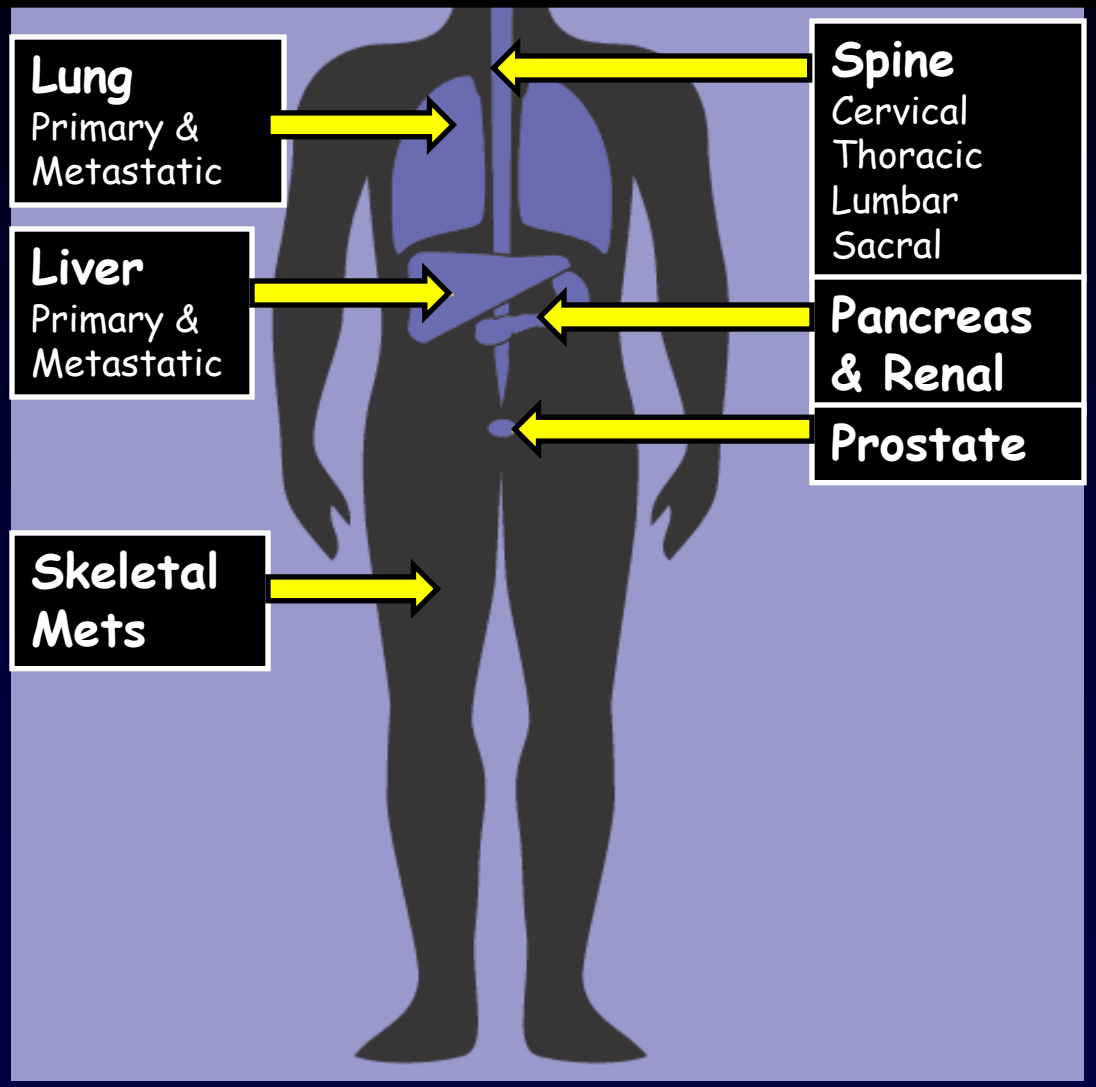
Moyed Miften, PhD
University of Colorado

Team

Kelly Stuhr
Bodo Reitz
Quentin Diot
Tracey Schefter
Laurie Gaspar
Brian Kavanagh

Rad Onc Staff at Univ. of Colorado

Clinical Applications of SBRT



SBRT Process in a Nut Shell

- Immobilization and Simulation
  - Motion Management
- Treatment Planning (TP)
  - Image Fusion
  - Planning Techniques (3DCRT, IMRT, Arcs)
  - Dose Calculation Algorithms
- Localization
- Treatment Delivery
- Quality Assurance

SBRT ≠ IMRT

- Ultra-high doses per fx, 10 to 20 Gy, in a hypofractionated regimen of 5 or fewer fxs
  - Errors will not be diluted

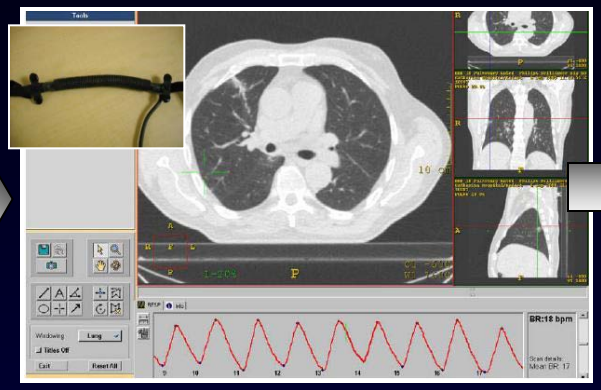
- Technically refined patient repositioning and treatment delivery procedures

Txt May Last Up to 45 mins

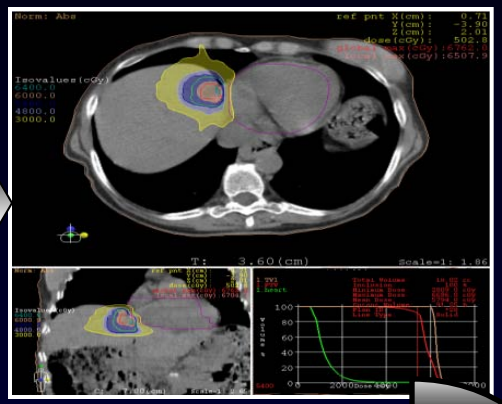
- Possible compromise in treatment efficacy for individual fxs that require long txt time
  - Tumor intra-fraction motion and patient involuntary movement during delivery
  - Theoretical risk of intra-fractional radiation damage repair within tumor cells in the context of prolonged fractional delivery
- Motion management is essential

SBRT Work Flow

Simulation



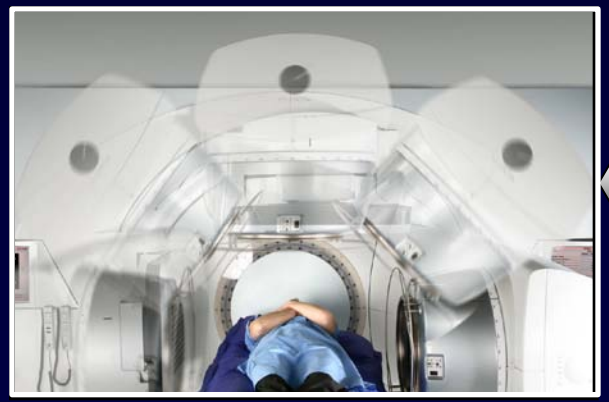
Motion Management



Planning

Localization

Motion Verification



Delivery

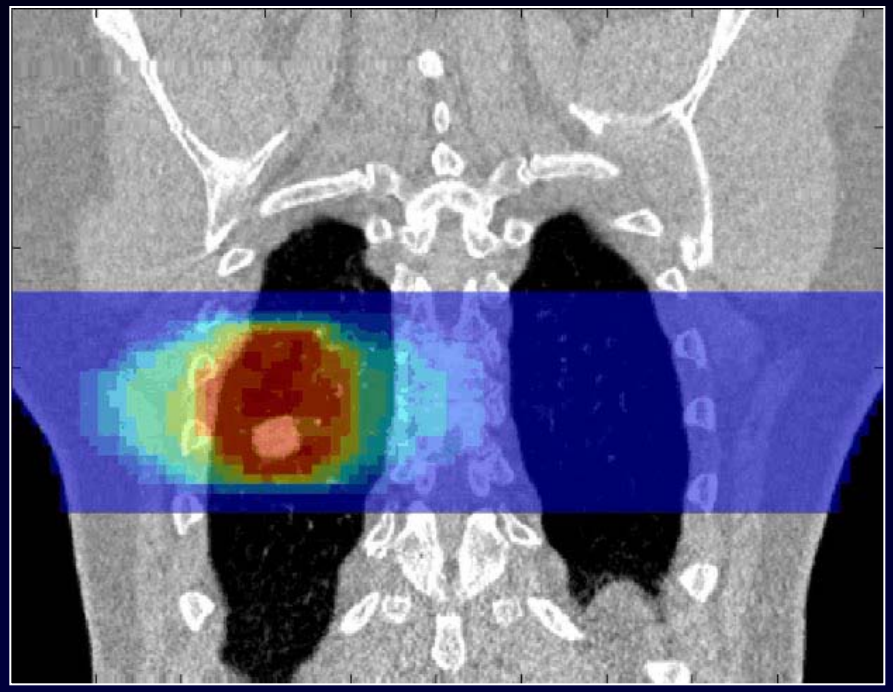
Immobilization/Simulation

- Scanning in TX Position
  - CT, MR, PET-CT
- Vac-Loc
- Motion Management
  - Abdominal Compression Plate
  - Pressure Belt
  - Body-Fix
- CT scan with ≤ 3 mm slice thickness

Tumors & Respiratory Motion

- Respiratory motion
  → significant intrafractional movement of organs in the abdomen
- Most prominent in lung and liver
- Traditionally (planning and delivery):
  large margins to account for motion

SBRT → Sparing of OARs becomes an issue



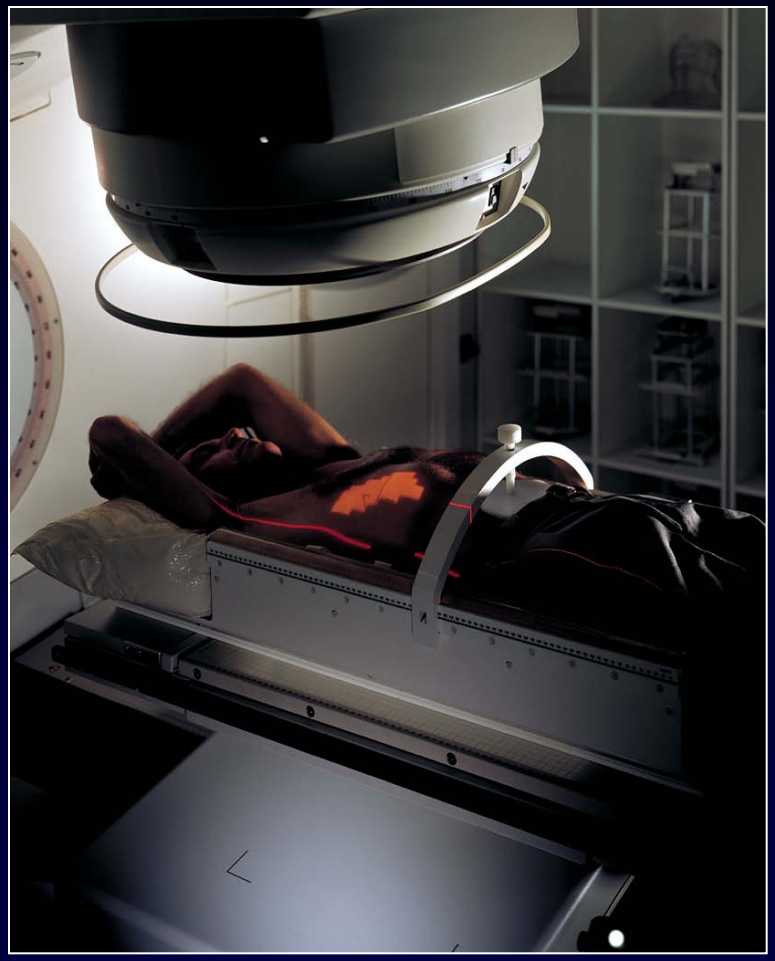
NSCLC Stage I

Ø GTV 2.1 cm, Excursion 2.5 cm

Motion Management and CT Simulation

- Forced shallow breathing techniques (Compression Paddle, Pressure Belt)
- Respiratory Gated CT and 4D-CTs
- Free Breathing and Slow CT-Scanners
- Free Breathing and Fast CT-Scanners
- Breath-Hold (BH) CT-Scans

Forced Shallow breathing – Abdominal Compression



- Stereotactic body frame
- Provided laser guided set-up: external fiducial localization
- Paddle used to induce shallow breathing
- Limitations of body anatomy

Body Fix

Elekta Medical Intelligence

Body Pro-Lok

CIVCO

Qfix Systems

Setup for Spine Patients

E.g. of a spine setup at the Univ. of Colorado

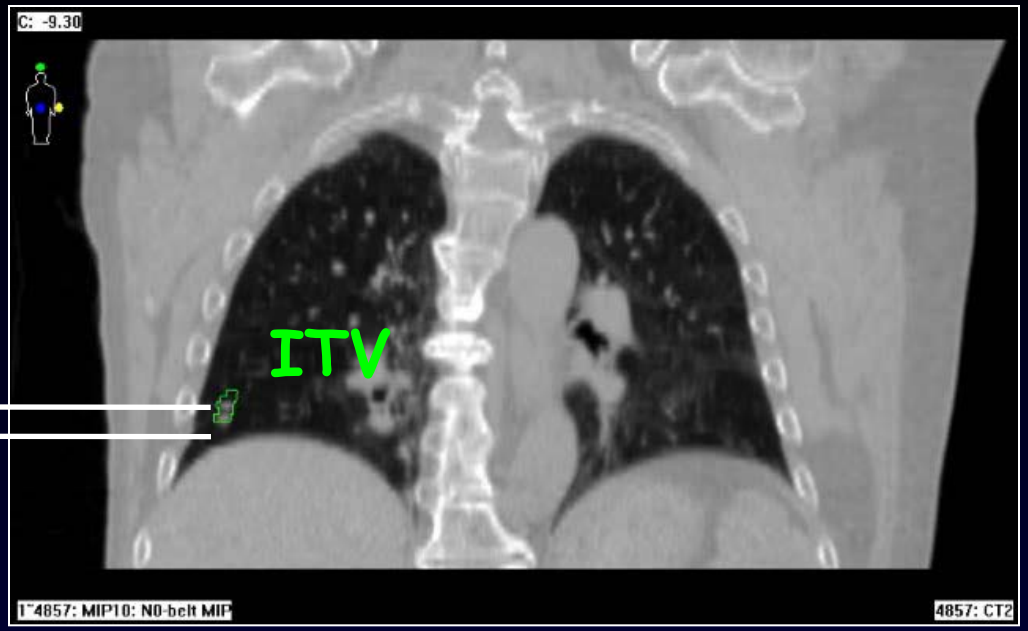
Compression Paddle

- Made of aquaplast material, metal plate, & Velcro belt
- Rigid & manually applied
- Not universally sized for all patients
- Difficult to apply on very thin & obese patients
- Marking of the patient & belt, and recording the belt extension

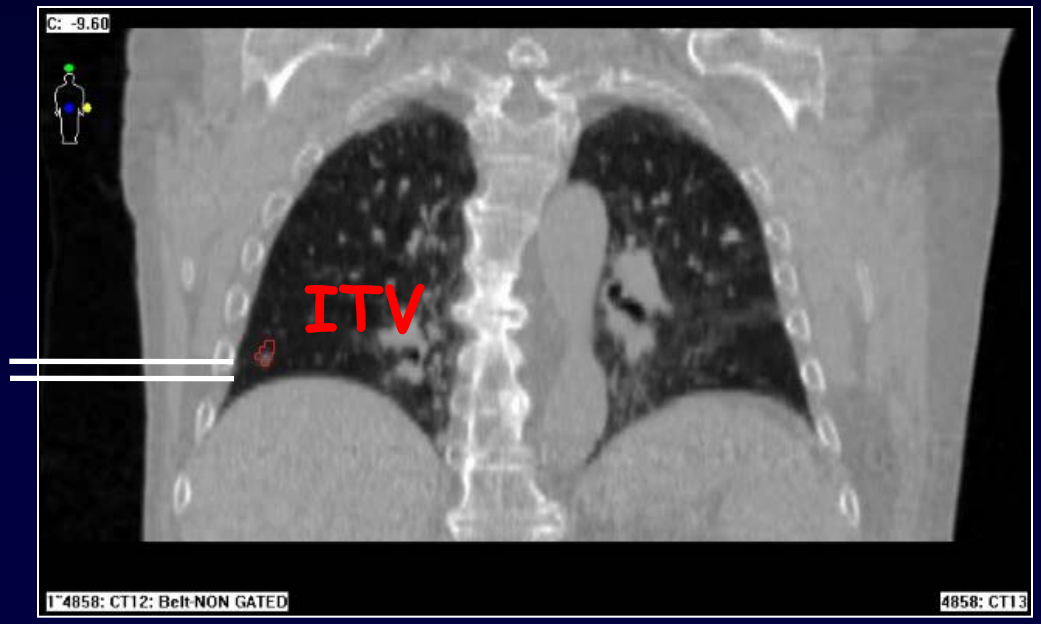
Pneumatic Compression Belt

- Air inflation bulb
- Pressure gauge
- Non-Rigid
- Marking of the patient skin & immobilization device
- Recording of the pressure
- Easy to use!

Less comfortable for patients as we are able to obtain more compression compared to the paddle



4DCT without Pneumatic Compression Belt



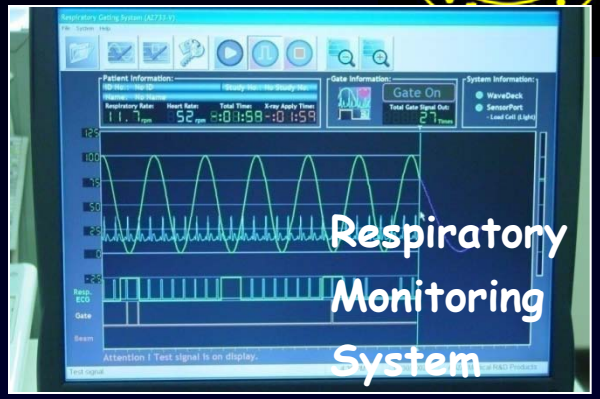
4DCT with Pneumatic Compression Belt

bar·ray personal radiation protection and accessories

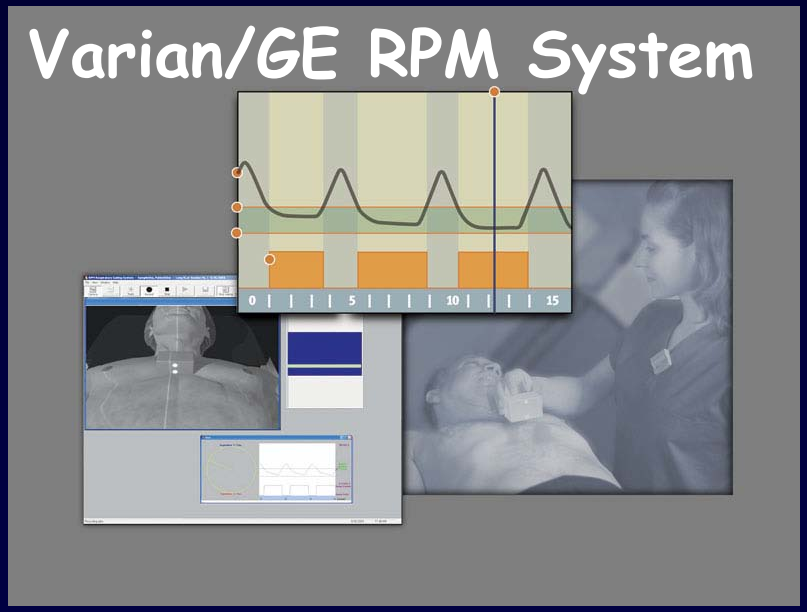
Compression Device

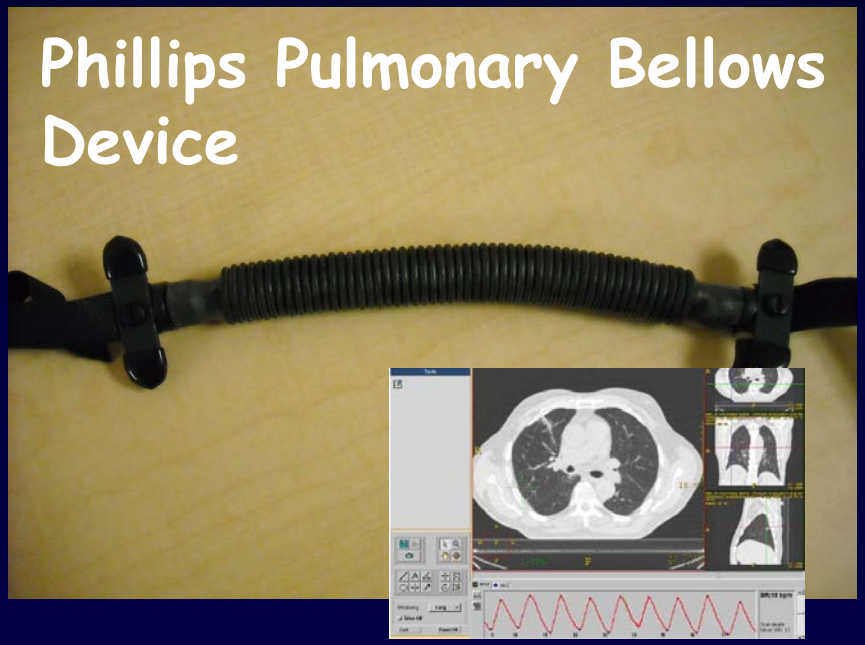
- Foam block
- Belt with plastic plate
- Air inflation bulb
- Pair balloons w/ cover
- Tubing

Respiratory Monitoring Systems



Siemens ANZAI Device

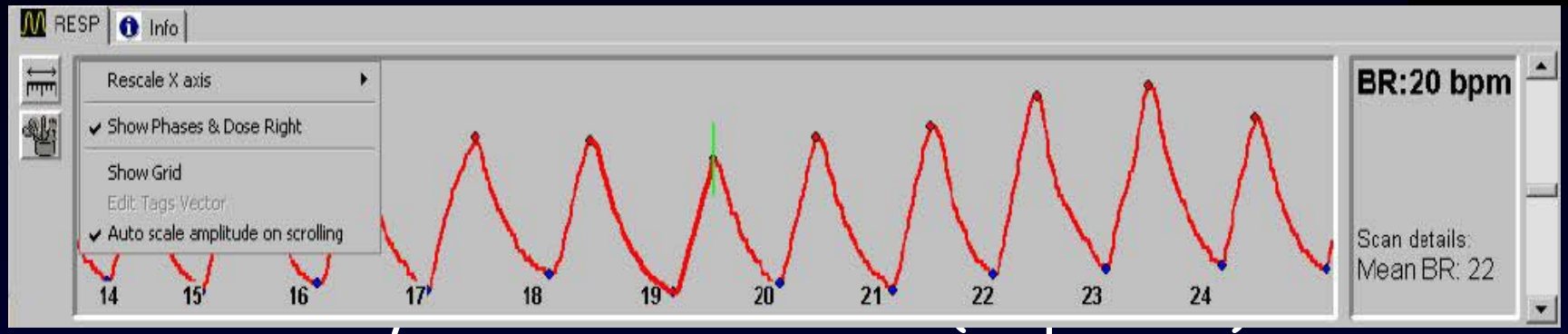




4DCT – What Do We Get

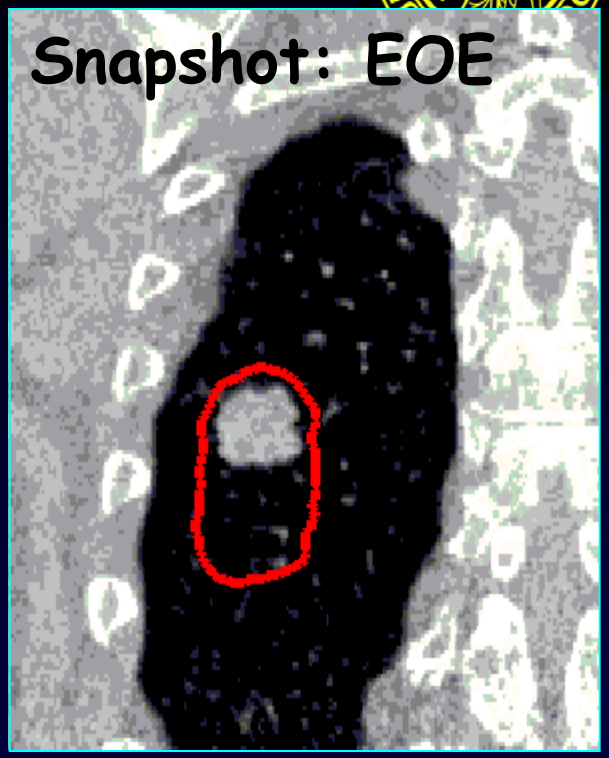
- Snapshots of selected breathing phases, including EOE, EOI, and everything in-between
- Average of all breathing phases (like slow CT)
- Combination of M out of N breathing phases (needed for gated RT delivery)
- Max/Min Intensity Projections (MIP/minIP)
- Visualization of the tumor motion over the whole respiration cycle
- Display of anatomy in space (3D) and time (4D)

Statistics from a 4DCT Scan



Pulmonary wave (during scan) statistics:		
	* scan length: 43.1 sec * 8 breath cycles were captured * Mean BR: 11 bpm * Breath rate range : 11 bpm - 11 bpm	* Average full exhalation phase : 83% * Average full inhalation phase : 98% * Amplitude range : 0.99 - 1.01 * Amplitude standard deviation : 0.01

Lung: Contouring ITV on MIP

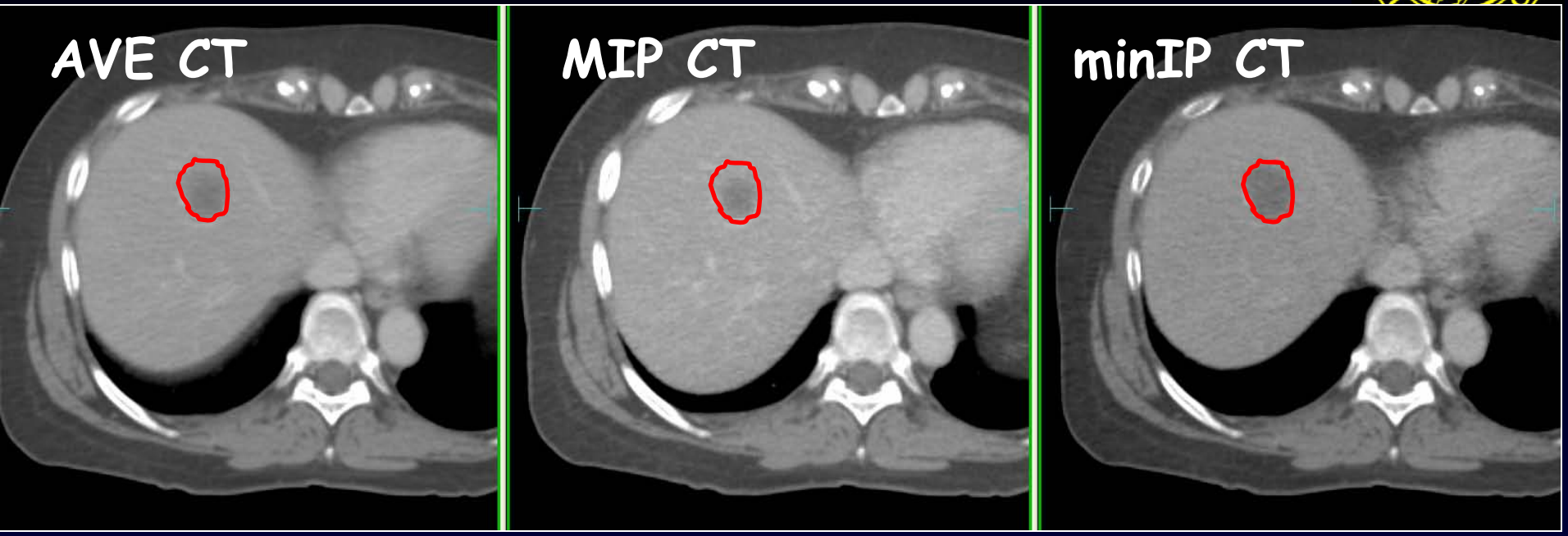


→ Contouring on Frozen Images is superior
- Better contrast (brightest voxels along the viewing ray)
- Avoids geometrical misses due to irregular motion

→ Fusion with FB (or Ave) may be necessary

→ Use of FB (or Ave) for dose calculations

Liver: Contouring ITV on minIP



→ Contouring on minIP is superior
- Better contrast (darkest voxels along the viewing ray)
- Display structures w/ low signal compared to surrounding structures

→ Fusion with FB (or Ave) with minIP may be necessary

→ Use of FB (or Ave) for dose calcs

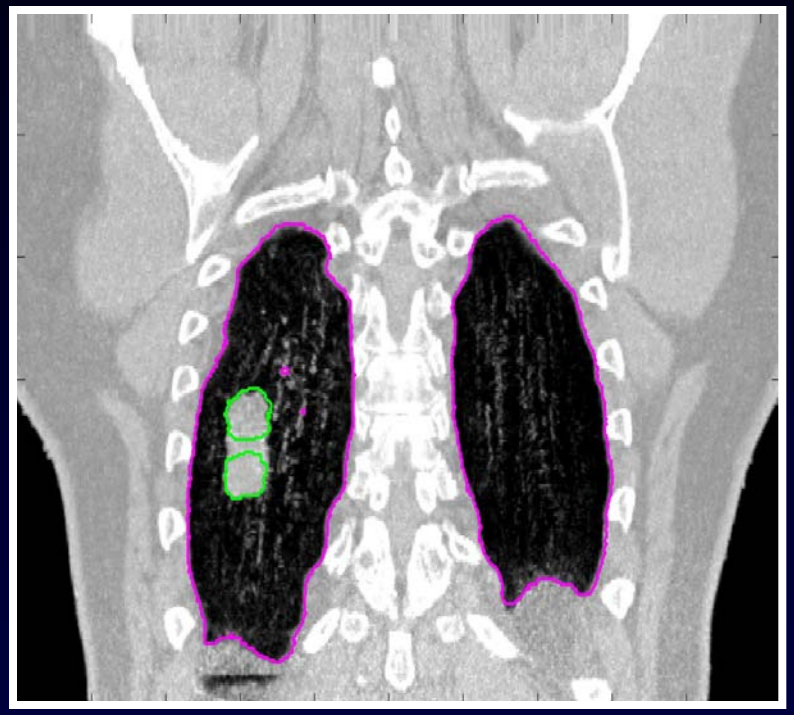
Slow CT Scans for SBRT

- Patient breathes normally
- Rotation time >> breathing period
- CT images are an average over all breathing phases
- Borders of organs tumor volumes can become diffuse

Observe target movement under fluoroscopy

Breath In … Hold Your Breath

- Voluntary BH: Patient to hold his breath at FI or FE
- Image acquisition must be completed while patient is holding his/her breath
- Requires Pt. cooperation
- CT images are a snapshot displaying one phase of the breathing cycle



- Often: EOE + EOI + FB scans are required (motion encompassing volume)

Poor man 4DCT

Multimodality Imaging for TP

- Lung and Liver
  - Likely: fusion with PET/CT diagnostic scans
    - Challenges
      - arms up vs. arms down
      - flat-table top vs. curved table top
      - uniform sampling
  - Preferred: fusion of planning CT with PET/CT scan in the treatment position
  - Ideal: PET/CT sim in the treatment position
- Spine
  - Fusion of planning CT with MRI

In-Room Imaging

Growing role of volumetric imaging before & during txt

+Image Quality

+Dose

CT on rails

XVI kV-CBCT

OBI kV-CBCT

TOMO MV-CT

Mvision MV-CBCT

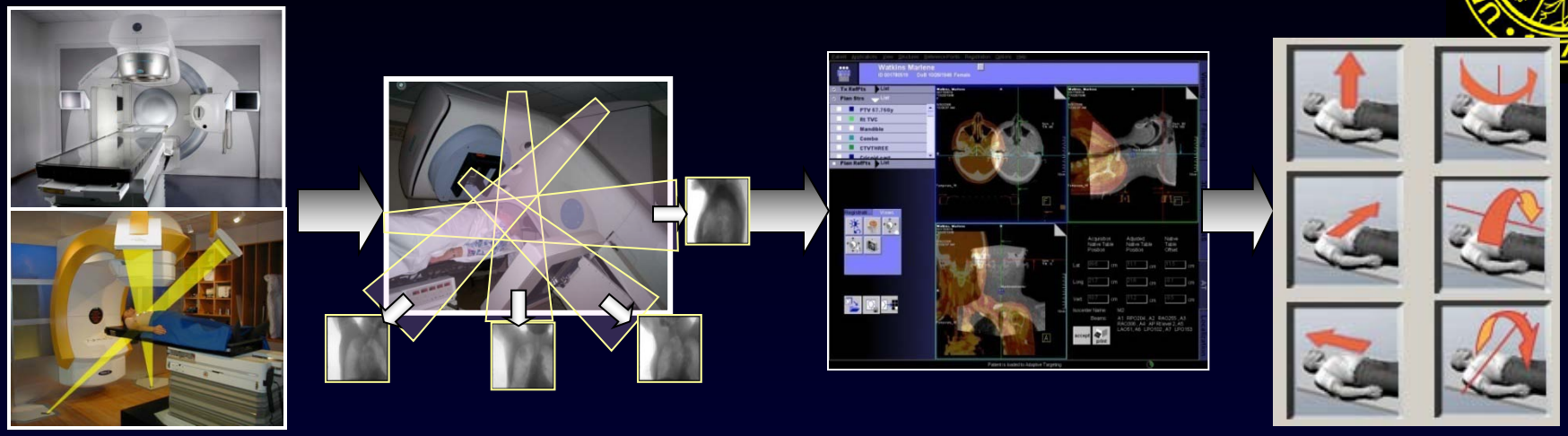
3D

Exac Trac

CyberKnife

2D

Localization



Acquisition Reconstruction Registration Table offsets

- Fusion shifts = table corrections needed to correct patient positioning
  - Translational shifts (Varian, Elekta, Siemens)
  - Translational shifts, pitch & roll (Novalis)
  - Translational shifts & roll (Tomotherapy)
  - Translational & rotational (Elekta w/ Hexapod table)

Localization w/ Fixed 2D kV Imaging

- kV oblique orthogonal images taken w/ patient positioned at ISO
- kV images fused to planning DRRs
- Table shifts to correct patient positioning
- Works well for boney anatomy (spine) & implanted fiducials
- Most soft tissues not visible w/o implanted fiducials
- Feature: continuous monitoring of tumor position

Novalis Exac Trac

Accuray CyberKnife

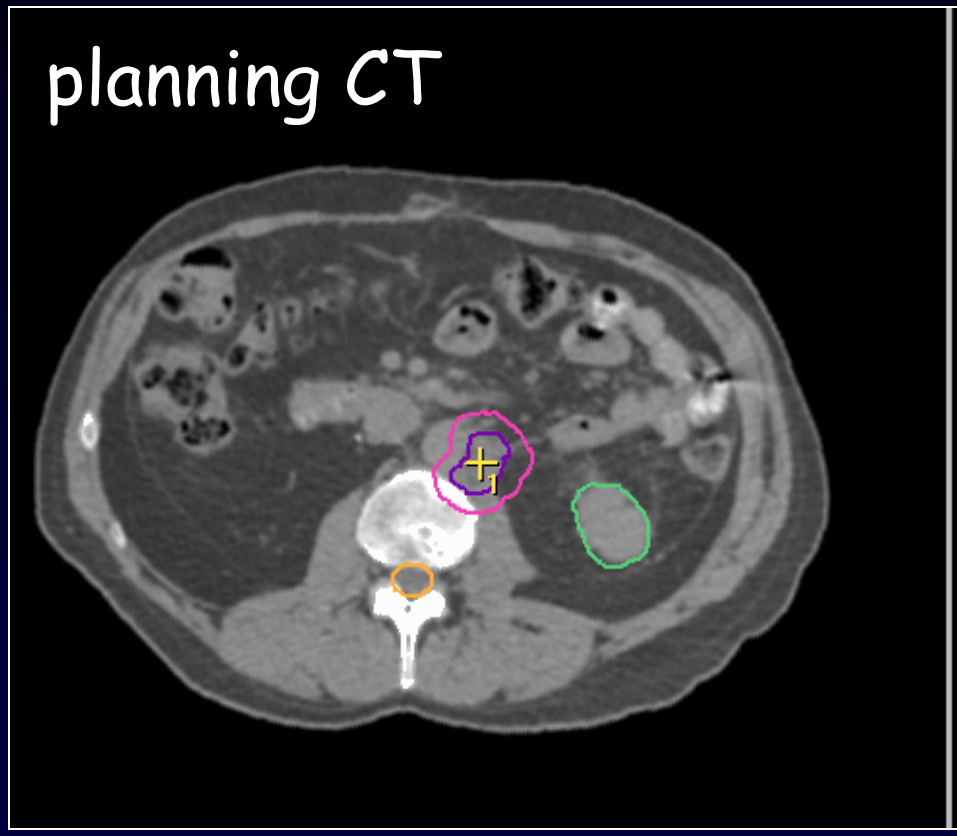
Localization w/ Volumetric Imaging (kV/MV-CBCT,MV-CT)

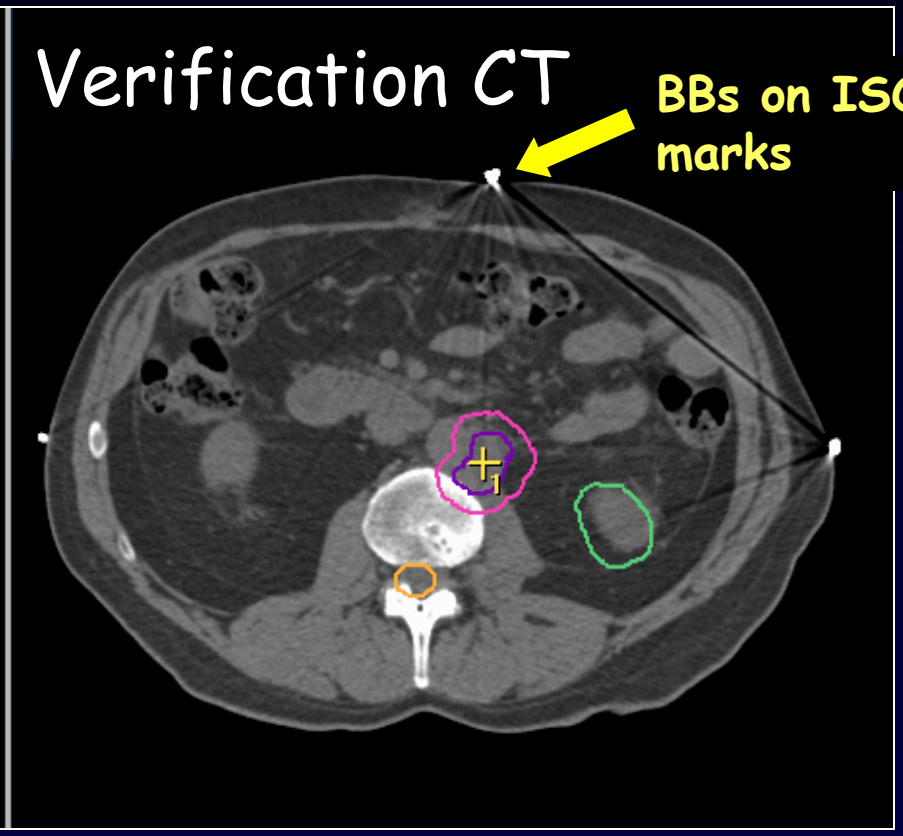
- Imaging of the tumor and surrounding OARs prior to Rx
- Compare Rx images to planning CT images to ensure accurate Rx delivery
- CBCT provides a 3D image of the tumor
- Motion and anatomical location can effect image quality

2D vs. 3D Localization

- kV 2D Imaging
  - Limited 2D information
  - Limited FOV of EPI does not always provide sufficient information for fusion process, resulting in erroneous results
  - Good fusions with bone and fiducials
  - Verification CT prior to treatment and external aides can help eliminate gross errors
- CBCT Imaging
  - Large amount of information = good fusions in tissue and bone
  - Subject to operator errors

CT Verification of ExacTrac 2D Fusion





Patient Misalignment is Apparent

Planning CT in Magenta

CBCT in Green

File Help

Coronal

Correction reference point = isocenter

Slice 205 of 410

Sagittal

Slice 202 of 410

Image

Slice Averaging

3 slices

Display Mode

Green-purple

GoTo ..

Transverse

Slice 131 of 264

8.15.2008 11:47:26.781 AM

Scan Time: ???? 12:00:00.000 AM

Reference Preset

Cor Ref Point ..

Scan

Alignment Clipbox

Structures ..

Alignment

Automatic

Manual

Reset

Convert To Correction

Position Error

Translation (cm)

X -0.66

Y -1.91

Z 0.00

Rotation (dg)

Table Correction

(cm)

Display controls

Level Loc 729.00

Window Loc 547.00

Slice 131

Zoom 1.36

Level Ref 1000.00

Window Ref 500.00

Dismiss

Accept

Repeated Localization Imaging?

- Treatment time → ~30 mins
  - kV 2D (e.g. Exac Trac) and CBCT
    - Image & localize → Treat → Image → Treat

The mean intrafraction tumor position deviation was measured as function of the interval between localization & repeated CBCT for 8 Pts

→ 5.3 mm if the time > 34 mins
→ 2.2 mm if the time < 34 mins

$p < 0.01$

ELSEVIER

Int. J. Radiation Oncology Biol. Phys., Vol. 68, No. 1, pp. 243–252, 2007

0360-3016/07/$–see front matter

doi:10.1016/j.ijrobp.2006.12.022

PHYSICS CONTRIBUTION

CONE-BEAM COMPUTED TOMOGRAPHY FOR ON-LINE IMAGE GUIDANCE OF LUNG STEREOTACTIC RADIOTHERAPY: LOCALIZATION, VERIFICATION, AND INTRAFRACTION TUMOR POSITION

Thomas G. Purdie, Ph.D.,*† Jean-Pierre Bissonnette, Ph.D.,*† Kevin Franks, M.D.,‡ Andrea Bezjak, M.D.,†‡ David Payne, M.D.,†‡ Fanny Sie, B.Sc.,§ Michael B. Sharpe, Ph.D.,*† and David A. Jaffray, Ph.D.,*†

Correction for Rotations?

Spine SBRT

- Evaluated impact of rotational setup errors on dose using 39 CBCT scans from 16 txts
- Cord PRV expansion of 2 mm assures safe txt delivery in the face of typically encountered rotations

Lung SBRT

- Evaluated translational and rotation errors for 8 Pts.
- Mean rotational variation was 0.1 ± 0.2°

ELSEVIER

Int. J. Radiation Oncology Biol. Phys., Vol. 73, No. 5, pp. 1596–1601, 2009

0360-3016/09/$–see front matter

doi:10.1016/j.ijrobp.2008.12.025

PHYSICS CONTRIBUTION

INFLUENCE OF ROTATIONS ON DOSE DISTRIBUTIONS IN SPINAL STEREOTACTIC BODY RADIOTHERAPY (SBRT)

Orit Gutfeld, M.D.,*[1] Annette E. Kretzler, M.D.,*[1] Rojano Kashani, M.Sc.,* Daniel Tatro, C.M.D.,* and James M. Balter, Ph.D.*

*Department of Radiation Oncology, University of Michigan, Ann Arbor, MI

Medical Dosimetry
Volume 35, Issue 1, Spring 2010, Pages 12-18

doi:10.1016/j.meddos.2008.12.003 | How to Cite or Link Using DOI

Image-Guided Stereotactic Body Radiotherapy for Lung Tumors Using BodyLoc With Tomotherapy: Clinical Implementation and Set-Up Accuracy

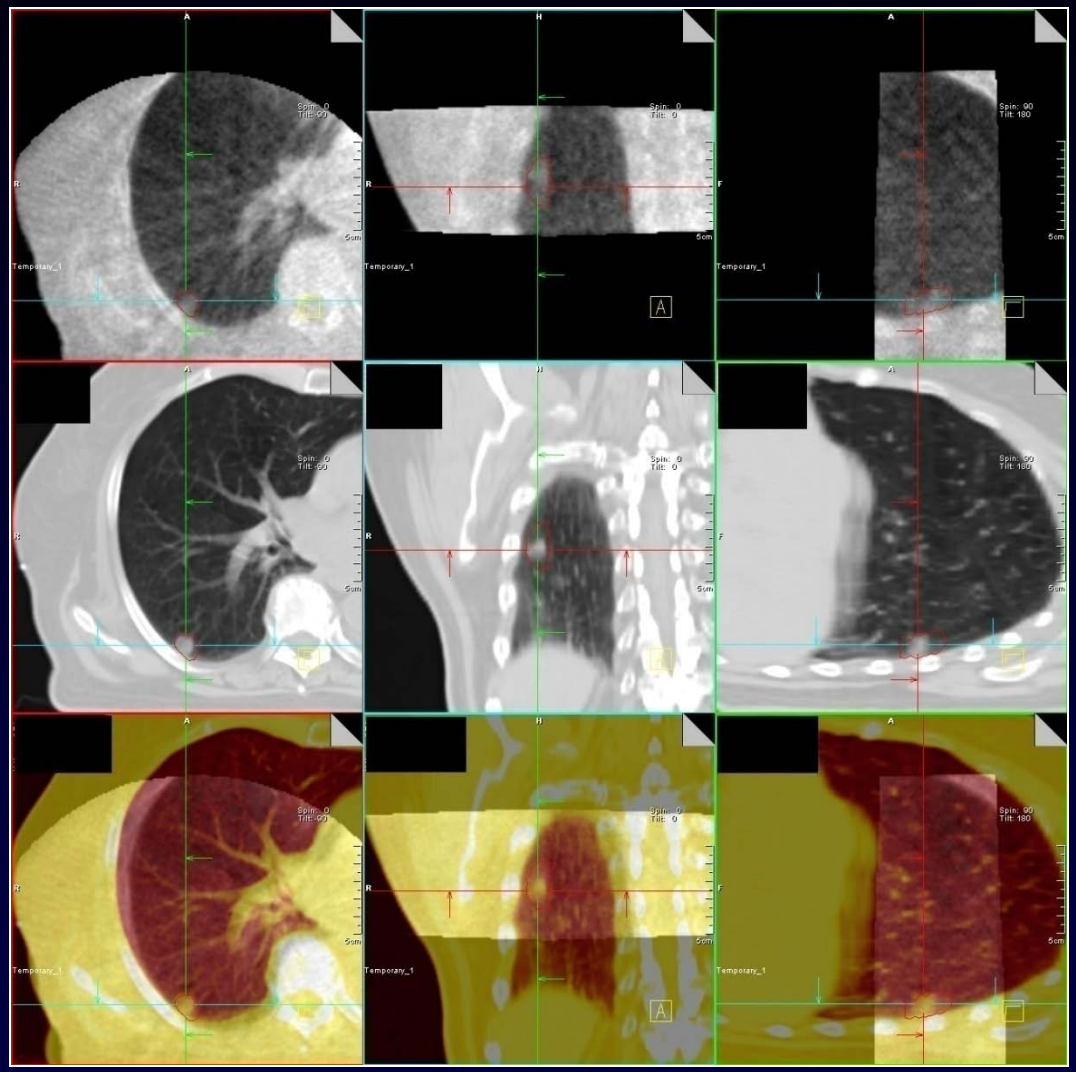
Jining Zhou Ph.D.[a], Barry Uhl M.D.[a], Kelly Dewitt M.D.[a], Mark Young M.S.[a], Brian Taylor M.B.A.[a], Ding-Yu Fei Ph.D.[a] and Yeh-Chi Lo Ph.D.[a]

[a] Center for Cancer Treatment, Sharp Grossmont Hospital, La Mesa, CA; Virginia Commonwealth University, Richmond, VA; Mount Sinai Medical Center, New York, NY

Received 28 May 2008; accepted 29 December 2008. Available online 30 January 2009.

Caution: Pts. might involuntary counteract the couch motion

4DCT Data & Localization



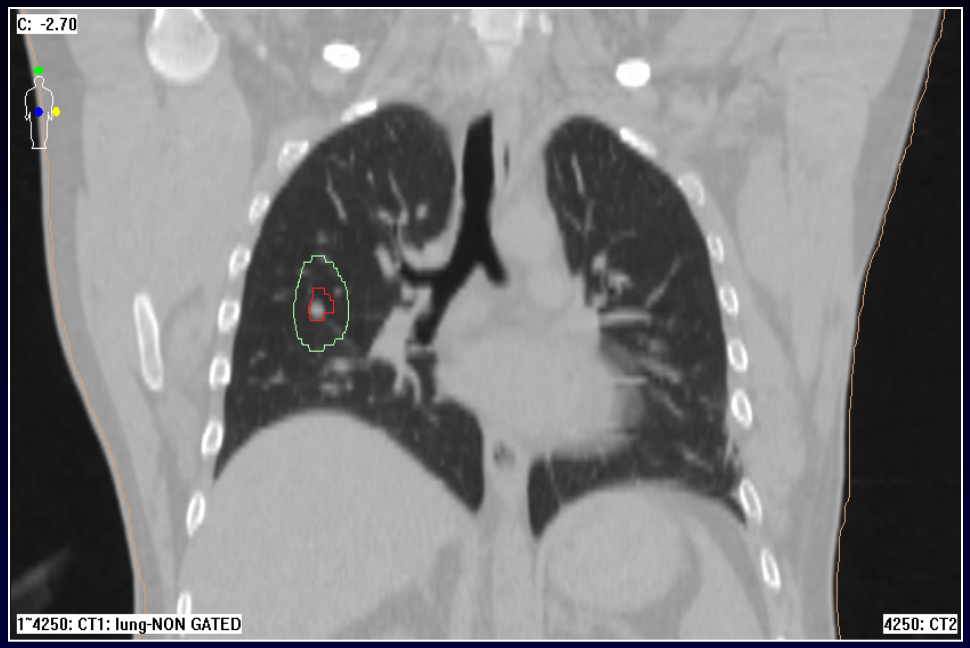
MV-CBCT

FB

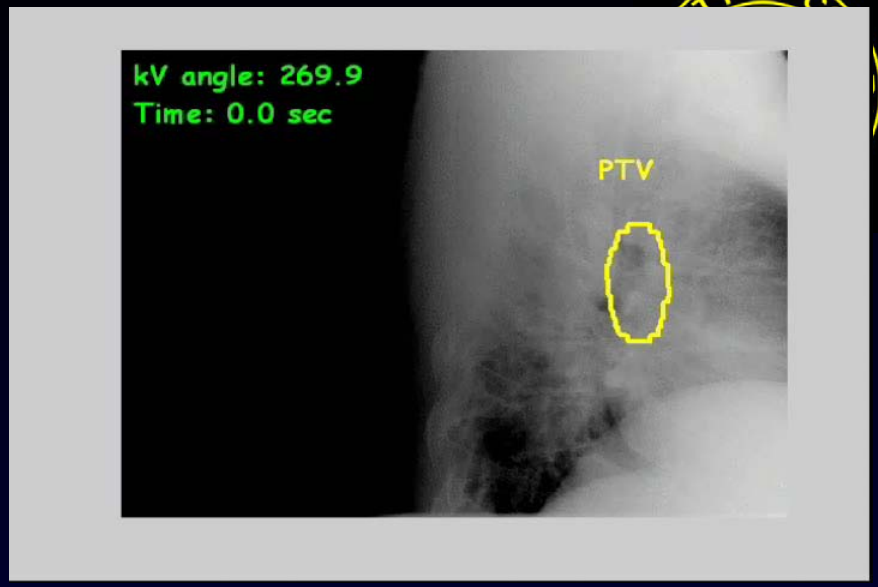
4DCT-ITV

Fused

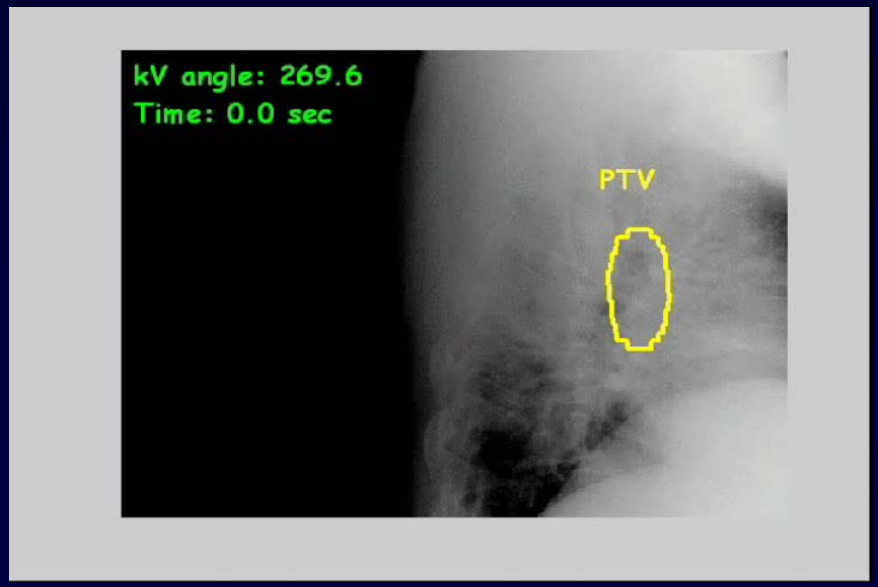
MV- & kV-Cine



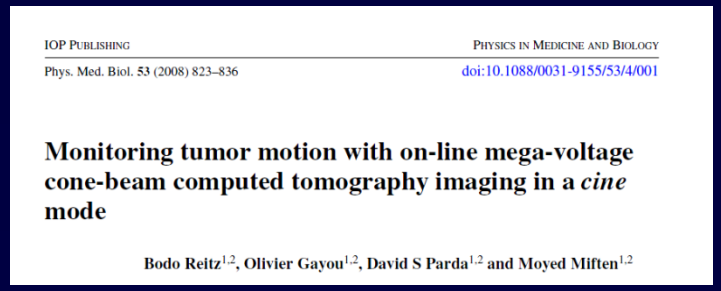
4DCT scan with Paddle



Without Paddle



With Paddle



IOP Publishing — Physics in Medicine and Biology

Phys. Med. Biol. 53 (2008) 823–836 — doi:10.1088/0031-9155/53/4/001

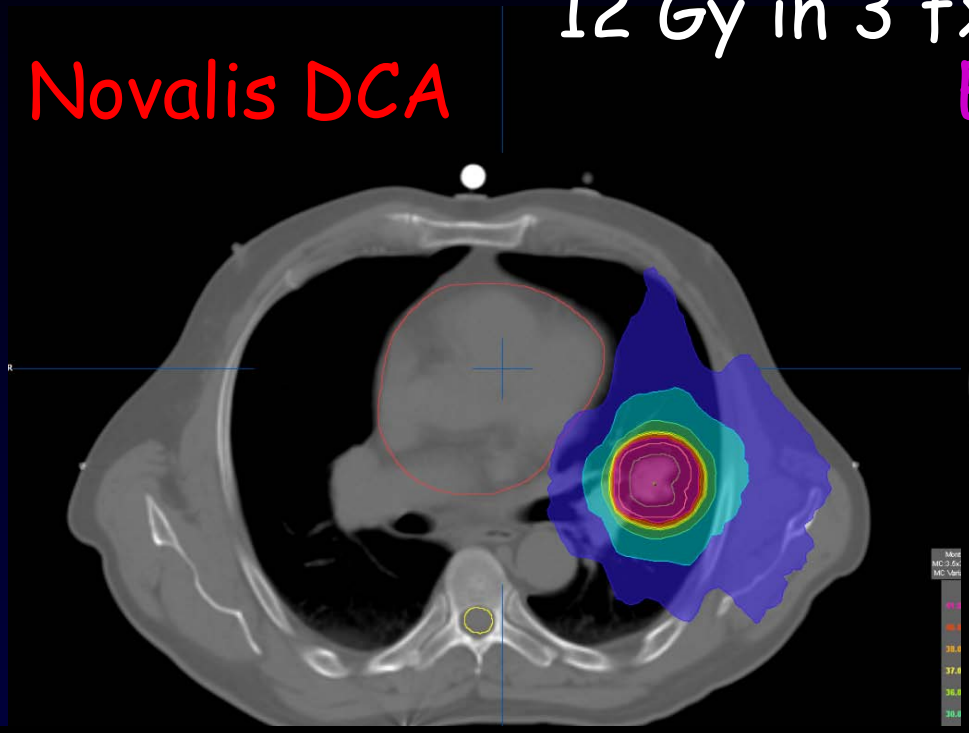
Monitoring tumor motion with on-line mega-voltage cone-beam computed tomography imaging in a *cine* mode

Bodo Reitz[1,2], Olivier Gayou[1,2], David S Parda[1,2] and Moyed Miften[1,2]

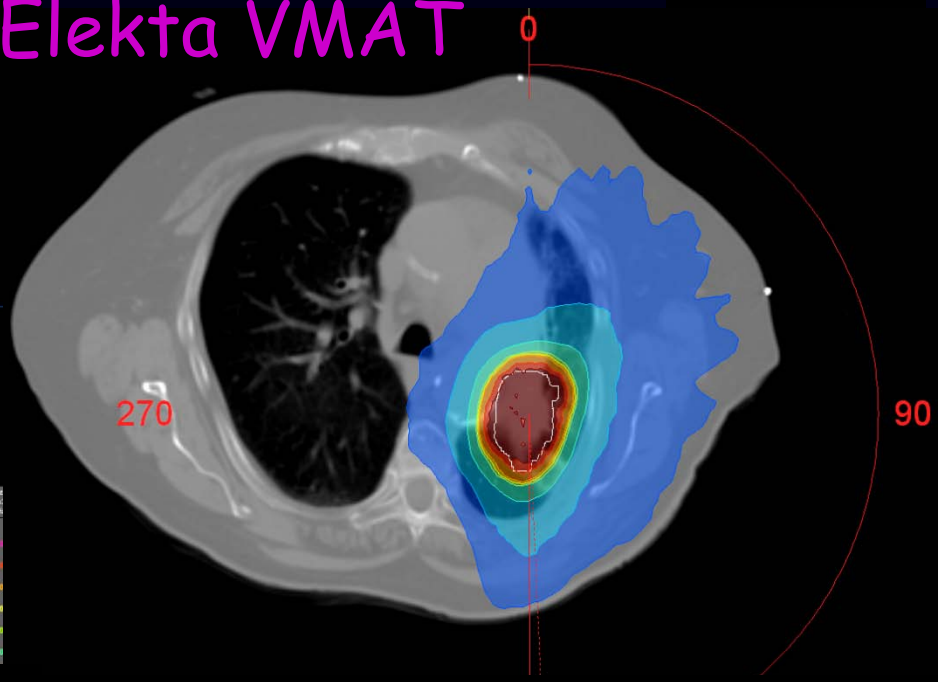
Rotation Delivery is Efficient

12 Gy in 3 fxs

Novalis DCA



Elektra VMAT



- # of MUs 2033
- Two partial DC arcs → 20-160 & 340-20 @ 90° Table
- Txt time ~6 mins

- # of MUs 2569
- # of segments 113
- One partial arc → 0-180
- Txt time ~6 mins

Conclusions

- SBRT is a complex treatment procedure
  - Team approach
- Accurate and comfortable patient setup and motion management procedures are essential
- Simple and effective solutions can be implemented to minimize setup errors and respiratory motion
- Key: Care must be exercised during the whole SBRT txt process

Thank You

University of Colorado Anschutz Medical Campus