4-D CT Based Treatment Planning in Lung

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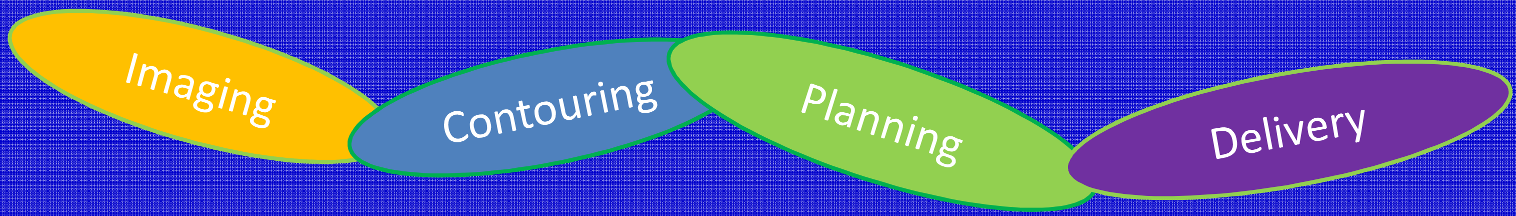
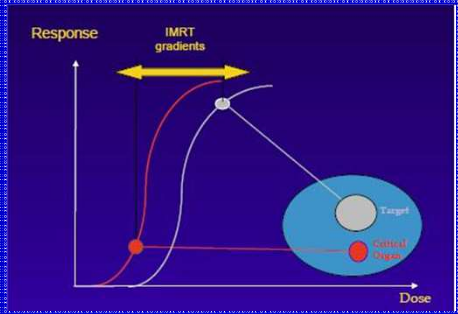
Introduction



- $Error_{Total} = Error_{Img} + Error_{Con} + Error_{Calc} + Error_{Del}$
- Error in one step is carried onto the other step
- Its essential to avoid errors in every step to keep the overall error small

Problems in Treating Lung Tumors



- Lung tumors are moving targets
- Continuously deforms (volume and position changes)
- Large margins are required to treat the target with out miss in conventional RT
- OARs at higher risk, reduces the possibility of achieving a higher TCP

Lung Cancer- are we delivering the right dose?

- Machtay *et al* have found that there is a 18% decrease in the risk of death for every 10 Gy increase in the BED (*Int J Radiat Oncol Biol Phys* 63(2):S66)

- Martel *et al* estimated that to achieve a 50% local progression-free survival at 30 months, 85 Gy is required (*Lung Cancer* 24(1):31–37)

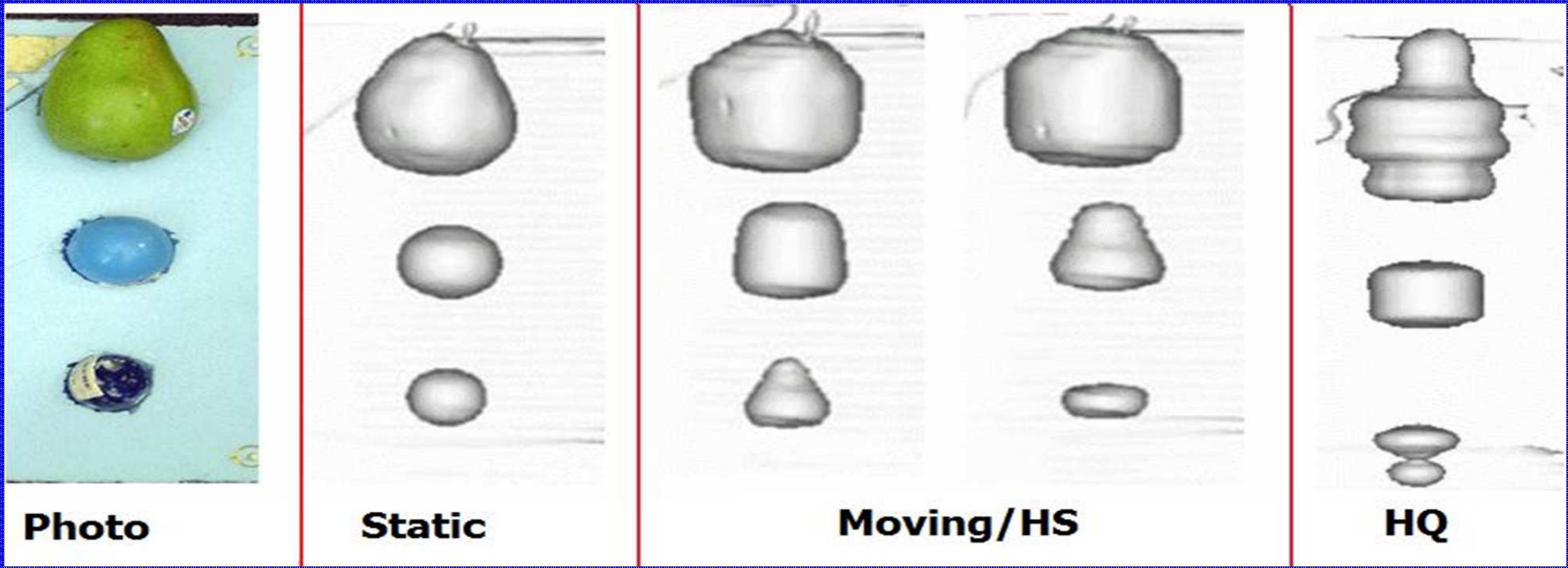
- Conventional radiotherapy limits the dose that could be delivered with acceptable complications *(around 60 Gy is delivered in most clinics)*

- There is an increasing importance to spare more critical structures due to the growing use of concomitant chemotherapy

Problems in *Imaging* with Moving Targets

- Distorts Target / OAR and provides incorrect positional and volumetric information

- Provides inaccurate HUs, leading to inaccurate dose calculation



Problems in *Planning* with Moving Targets

- Conventional planning methods use a sufficiently large margins to account for target motion *(sub optimal)*
- This increases the field size and in turn increases the dose to normal tissues
- Impossible to assign a patient-specific internal target volume *(ITV)*
- Limits the dose that is required to achieve high control of disease

Problems in *Treatment Delivery* with Moving Targets

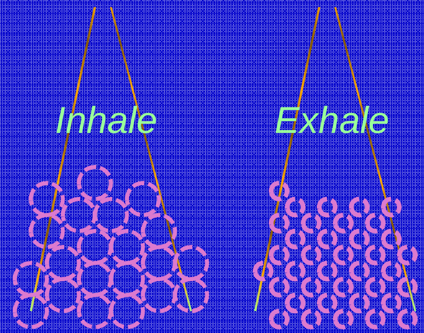
- Intrafraction organ motion causes dose blurring/averaging of the static dose distribution

- For non-IMRT treatments the dose is blurred and increases the beam penumbra

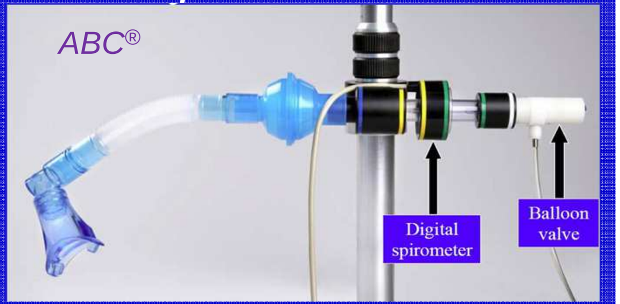
- This effect is exacerbated in IMRT treatments

Techniques Available for Respiratory Management

- Motion-encompassing methods
  - *slow CT, inhale and exhale breath-hold CT & 4-D CT*



- Respiratory gated techniques
  - *RPM ®, ExacTrac Gating / Novalis ® Gating, internal fiducial markers (Calypso ® system)*



- Breath-hold techniques
  - *ABC®, verbal coaching*

- Forced shallow-breathing methods
  - *With abdominal compression*
- Respiration-synchronized techniques
  - *Dynamically varying the MLC leaves to synchronize with tumor movement*

Why use 4-DCT?

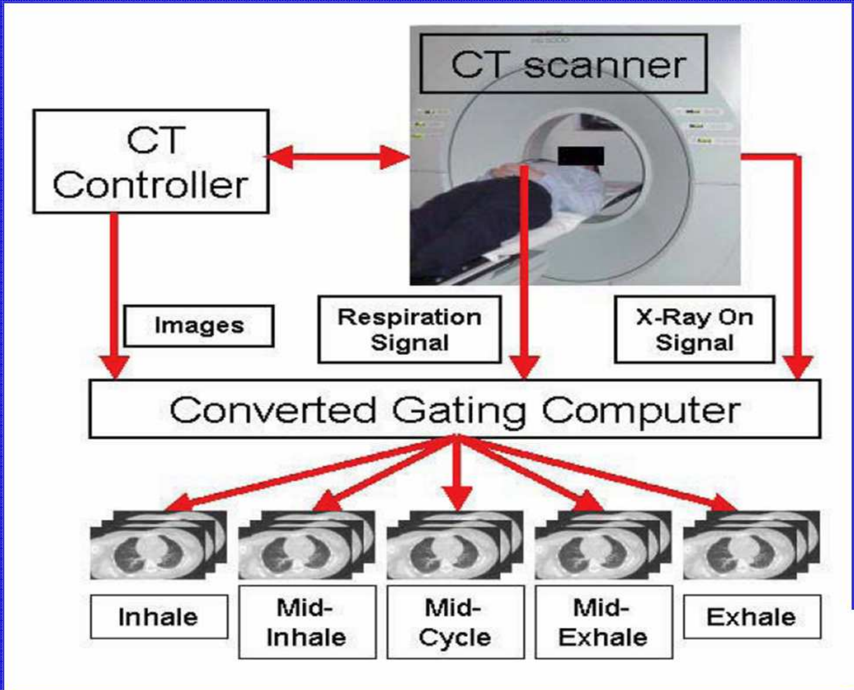
- Breath-hold techniques not suitable for all patients
- Increases the overall treatment time
- Slow CT provides distorted images (lesser resolution)
- 4DCT provides high resolution with spatial & temporal information, enabling tracking & gating delivery

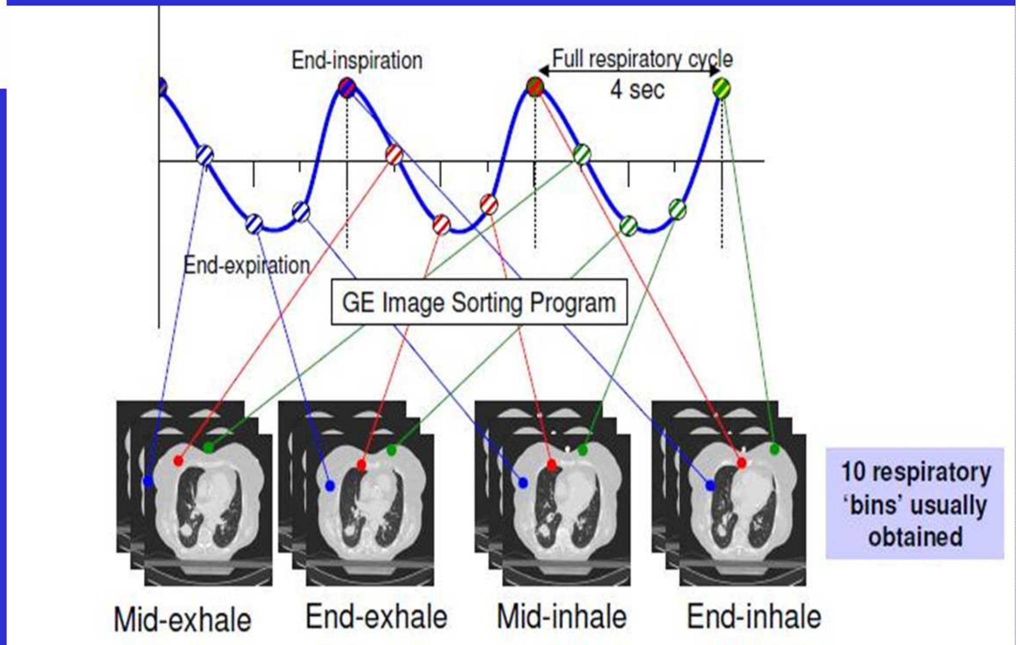
What is 4-D CT?

- Its not an entirely different CT
- **4DCT = Conventional CT** + A**dditional system**

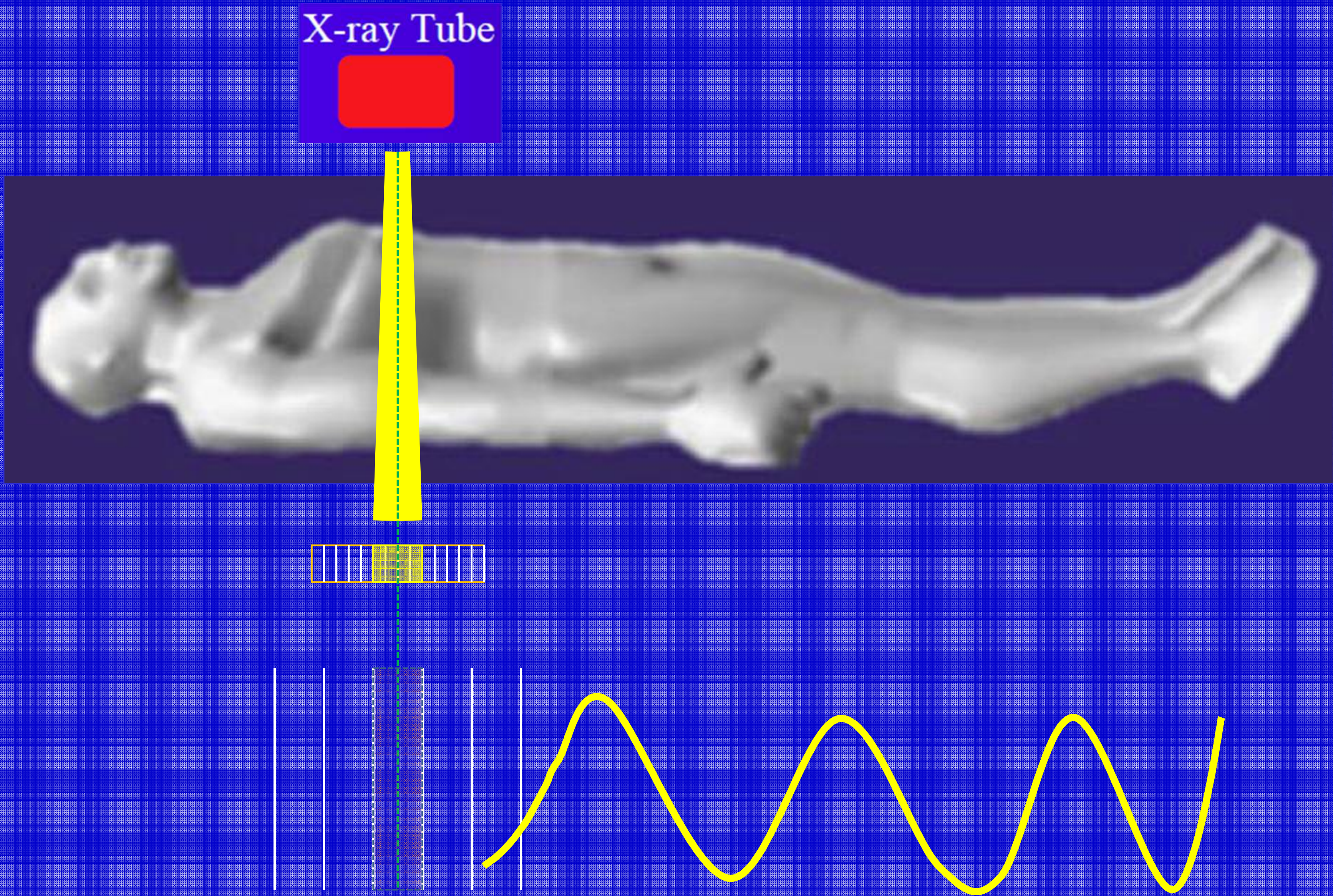
  (for acquiring respiratory information)
- An imaging system for obtaining respiratory-correlated images
- Assumes that organ motion such as lungs can be related to an external marker

4-D Acquisition process

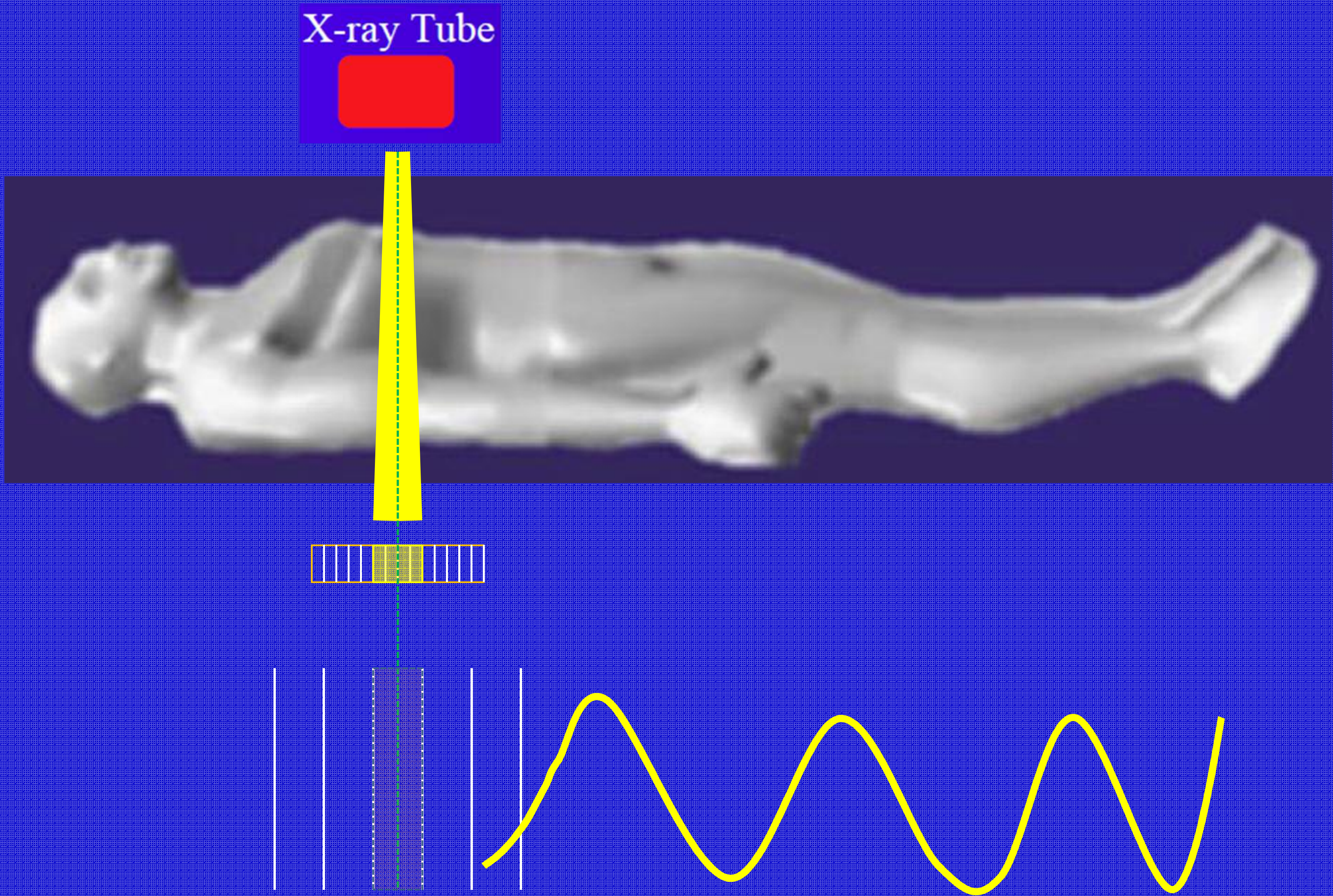




Prospective Acquisition process…



Retrospective Acquisition process…



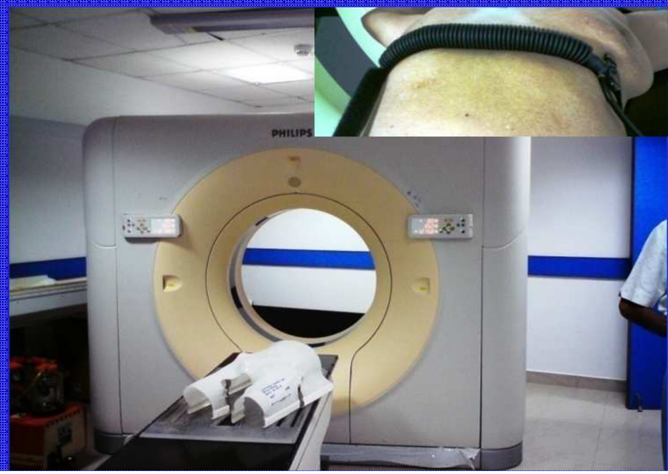
Pros & Cons of 4-D CT

- ✓ Motion artifacts are reduced
- ✓ Tumor and organ spatial & temporal information available
- ✗ Imaging dose
- ✗ CT tube heating
- ✗ Data management
- ✗ Artifacts created by irregular breathing

Systems to obtain 4-D CT

Commercially available systems

- ***GE***
  (RPM)
  Image sorting
- ***Philips***
  (RPM+ Bellows)
  Sinogram sorting
- ***Siemens***
  (Abdominal belt)
  Sinogram sorting
- ***Toshiba***
  (Abdominal belt)
  Image sorting



Planning process…

4-D Imaging

Train the patient to breath regularly

↓

Setup/immobilize the patient in the treatment position

↓

Place bellows / infra-red marker over the diaphragm

↓

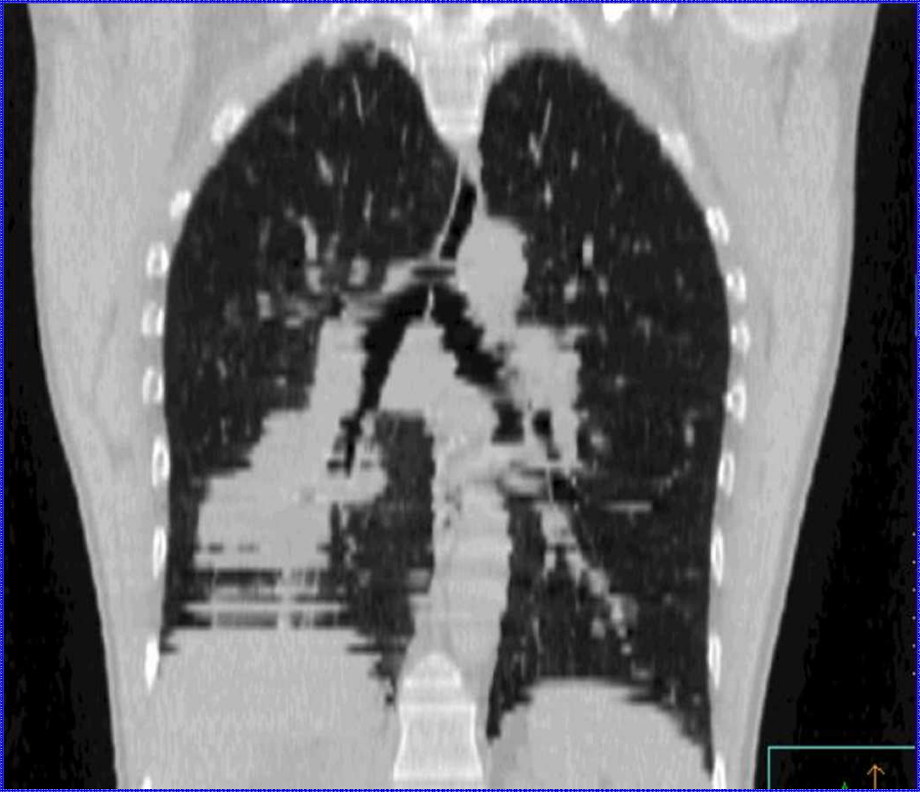
Acquire the images at different phases *(retrospective scanning)* or at a particular phase *(prospective scanning)*

↓

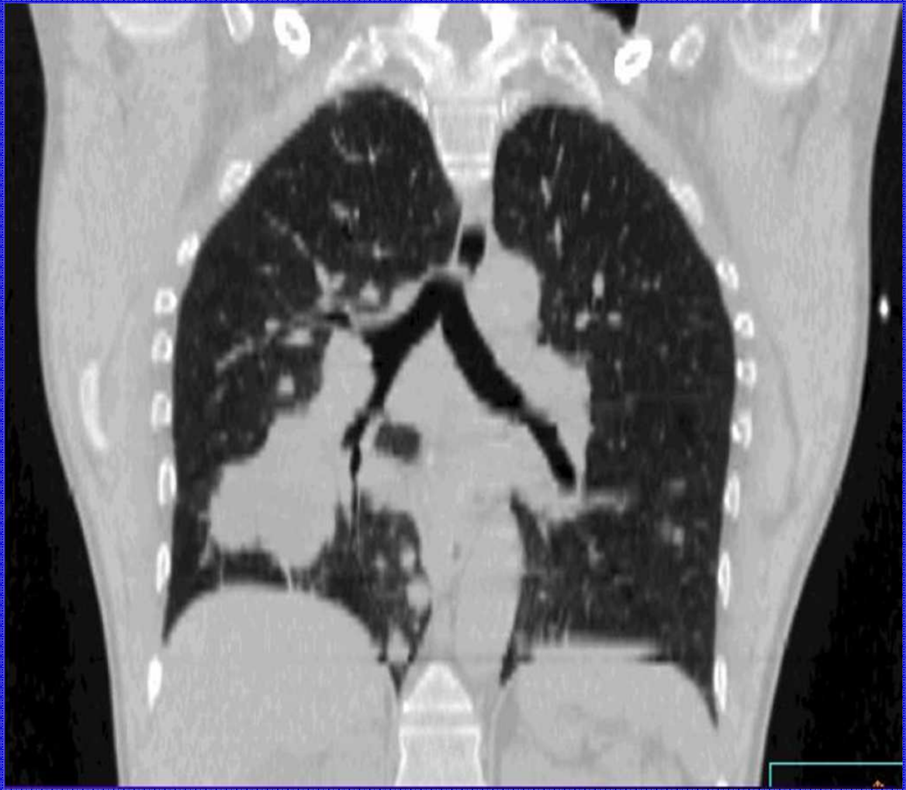
System sorts the images into different 3D image sets with the help of respiratory signal

(either sinogram or image sorting, sinogram sorting reduces artifacts)

Image Difference



Un-Gated



Gated

Keall et al Aust Phys Eng Sci Med 2002

Differences between 4D & 3D Imaging

Process/step	3D scanning	4D scanning
Patient positioning	As currently performed	No change
Use radio-opaque seeds	As needed	No change
Scan – light breathing	Acquire ~100 slices 1 volumetric study	Acquire 1500+slices – multiple volumetric studies
Dose	~1 cGy	3–5 Times greater dose
Reconstruction	Conventional	Conventional followed by resorting/multiple sets OR projection sorting followed by conventional reconstruction
Image fusion with other studies	Complex problem	Complex problem
Contouring VOIs	Performed on single study	Performed on multiple studies; computer assistance needed
Aperture design	Standard 3D	Extract shape and trajectory; create composite ITV
Choose beam directions	BEV	Multiple/composite BEV – minimize motion effects
Generate DRRs	Conventional	At specific phase or pseudo fluoroscopic DRR movie loop
Image guided patient set up	Standard guidance by bony anatomy or clips	Guidance by gated or multiple image acquisitions (compare DRRs)

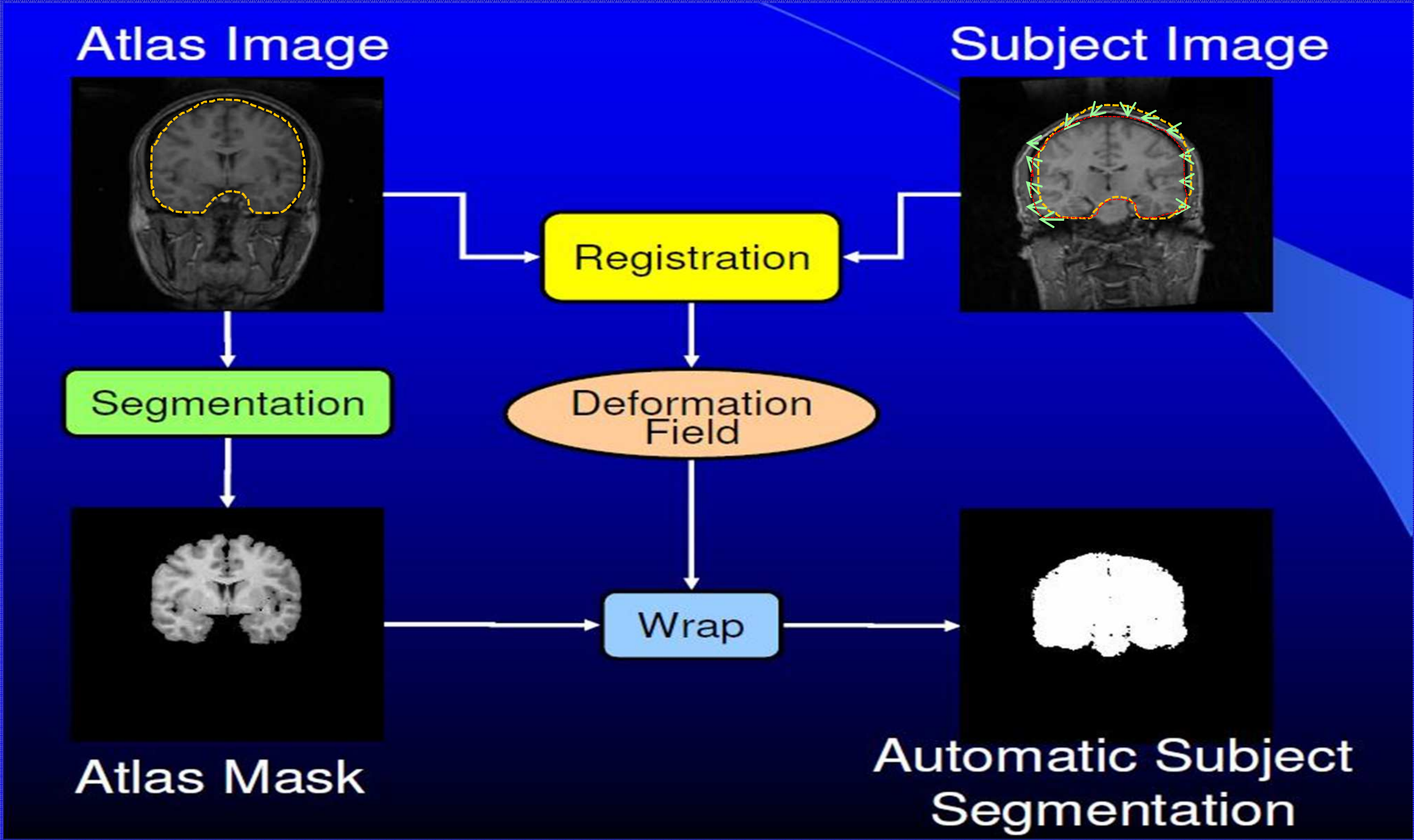
Taken from Image-Guided IMRT, Thomas Bortfeld · Rupert Schmidt-Ullrich · Wilfried De Neve · David E. Wazer (Eds.),Springer

Margins for 4-D Planning

- 4-D CT is temporarily discrete with typically 8-15 respiratory phases
- Continuous temporal changes are discretized and interpolated *(accuracy unknown)*
- Artifacts are introduced due to irregular respiration
- Deformable Image Registration used for auto-contouring has its own limitations

Deformable Image Registration

Basically non-rigid image registration algorithms



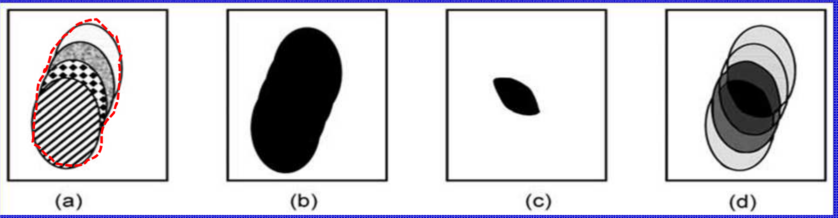
Planning method-1

Create Maximum Intensity Projection *(MIP for lung)*

Contour CTV on MIP *(actually CTV + IM)*

Assign a setup margin *(3-5 mm for lung, 1 SD)* , this makes up the PTV

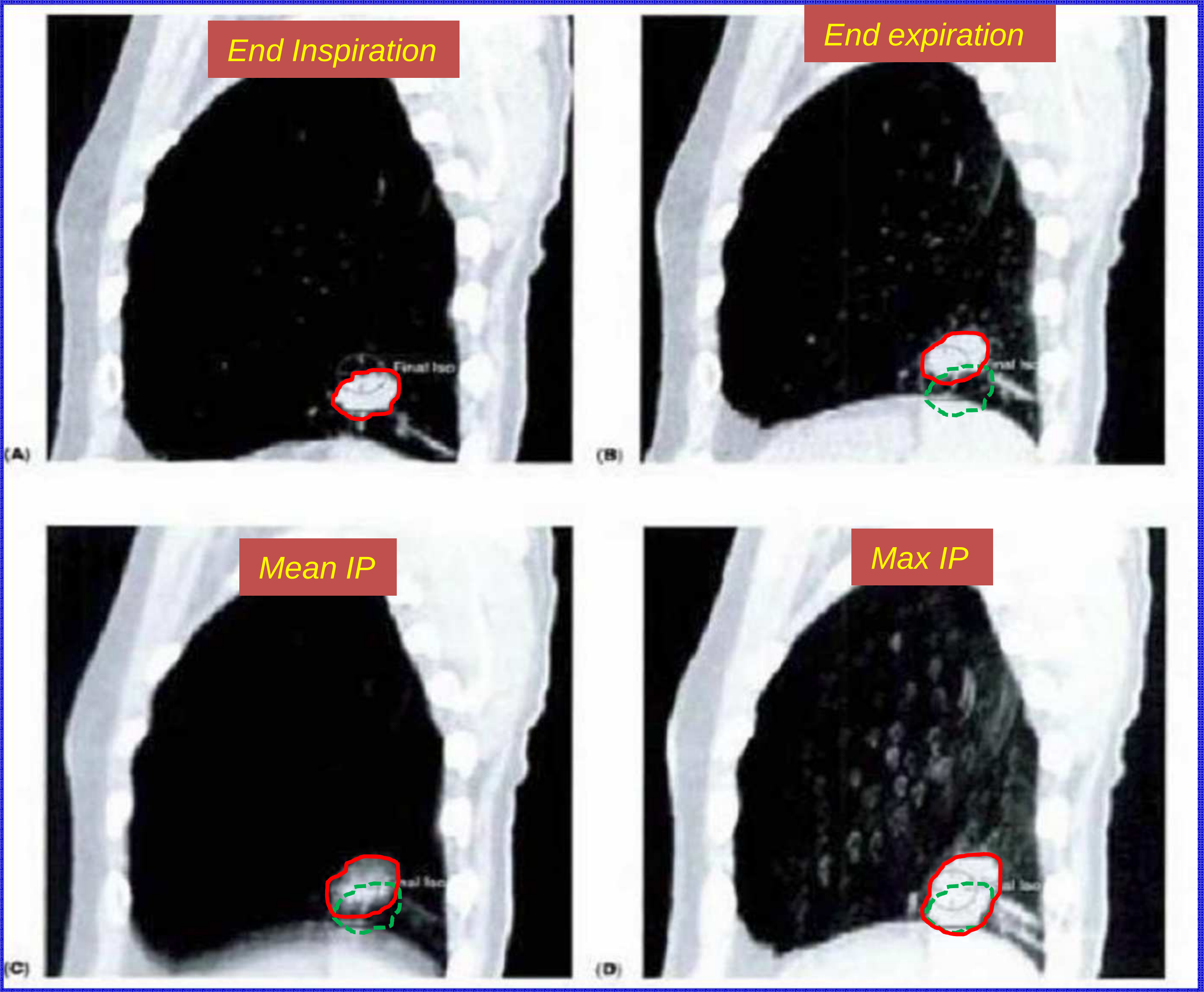
Plan and treat



Underberg et al , *Int. J. Radiation Oncology Biol. Phys., Vol. 63, No. 1, pp. 253–260, 2005*

Separate phases *MIP* *Min IP* *Mean IP*

Lung GTV in different phases & Image Sets



Planning Method-2

Contour target & OARs in single phase *(exhale preferred)*

⬇

Use *Deformable Image Registration* to auto-contour on all other phases *(auto-contouring)*

⬇

Plan in one phase and auto-plan in all other phases with 4-D BEV *(using macros/scripts)*

⬇

Verify all the plans manually, in some plans OARs may be irradiated and may not be in others

Planning Method-2…

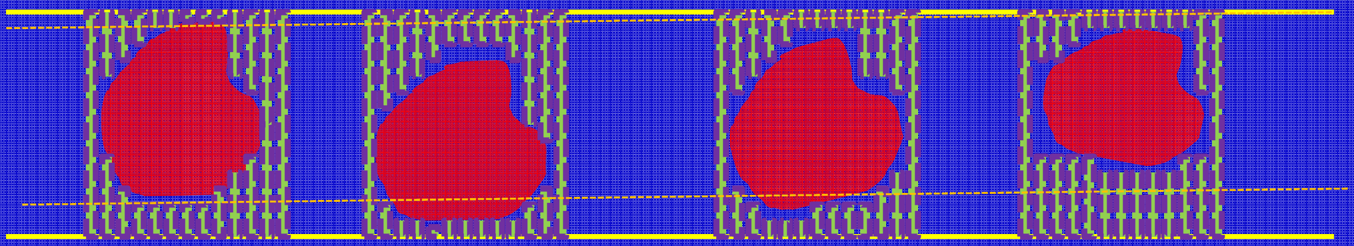
Sum the dose distribution with the help of displacement vector fields (DVF) *(weighted by the fraction of time spent in each respiratory phase)*

⬇

Evaluate the final 4-D plan and if necessary modify the plan

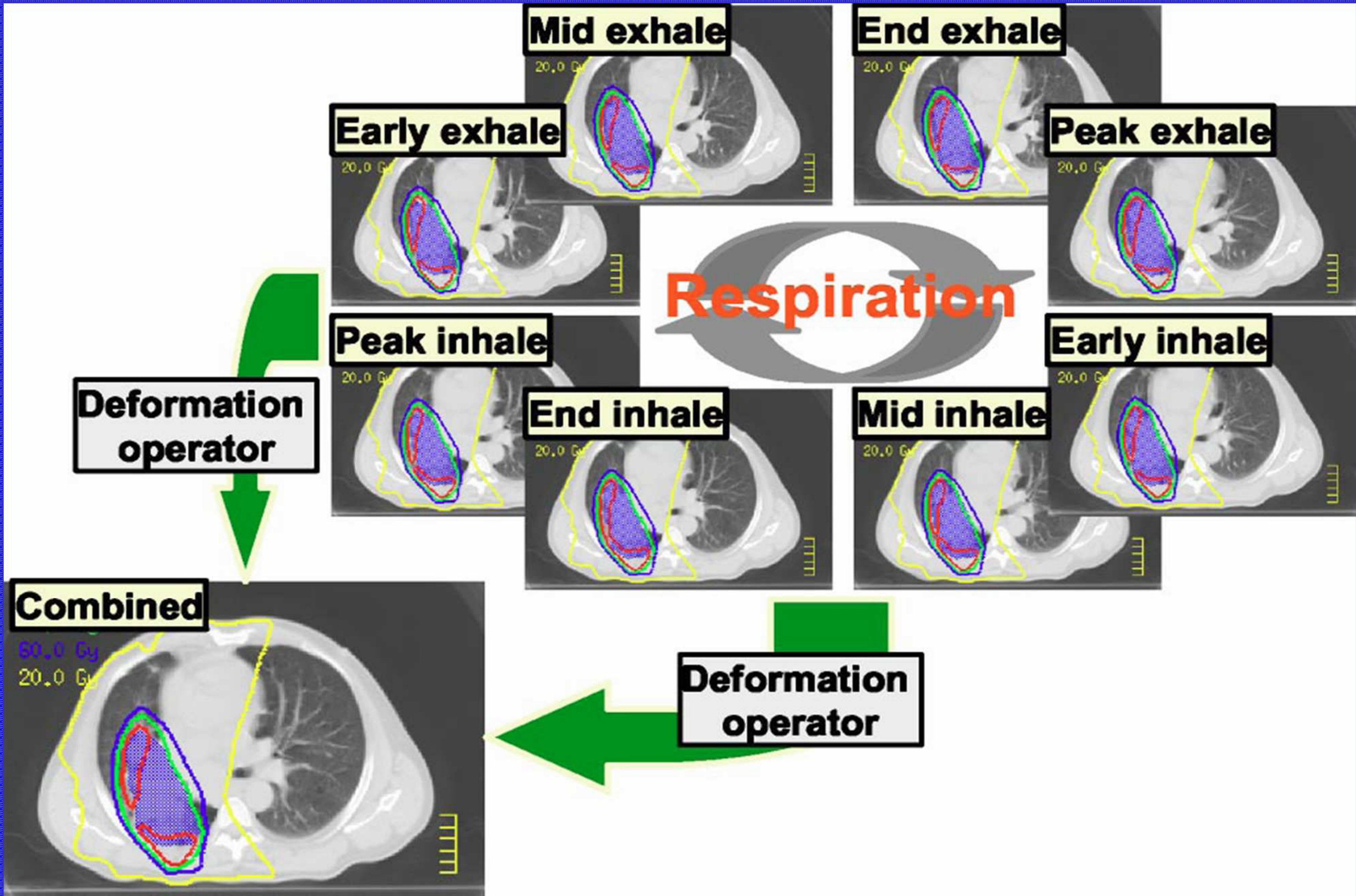
⬇

Treat *(either Gate / Track)*



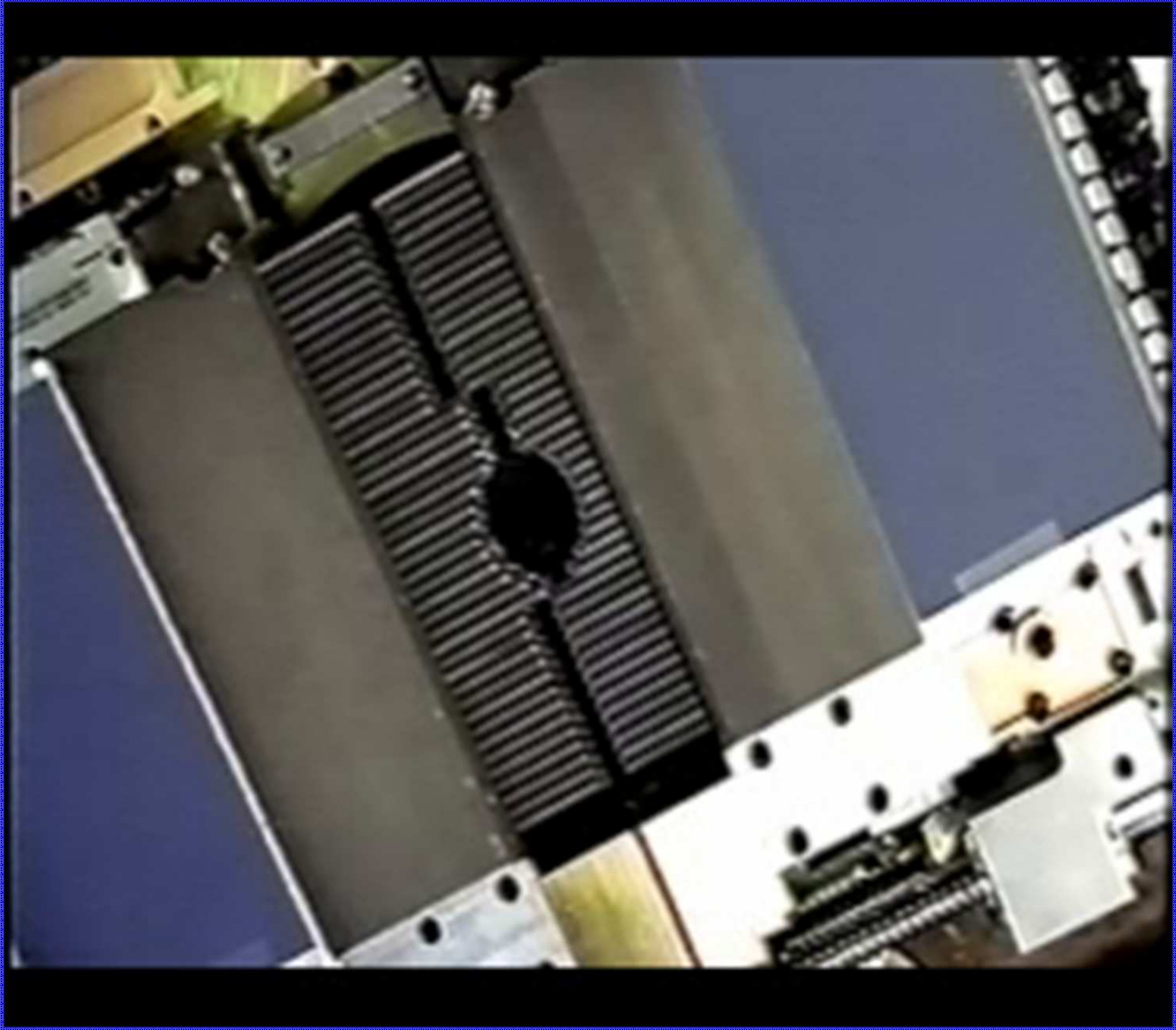
BEV for different phases (4D BEV)

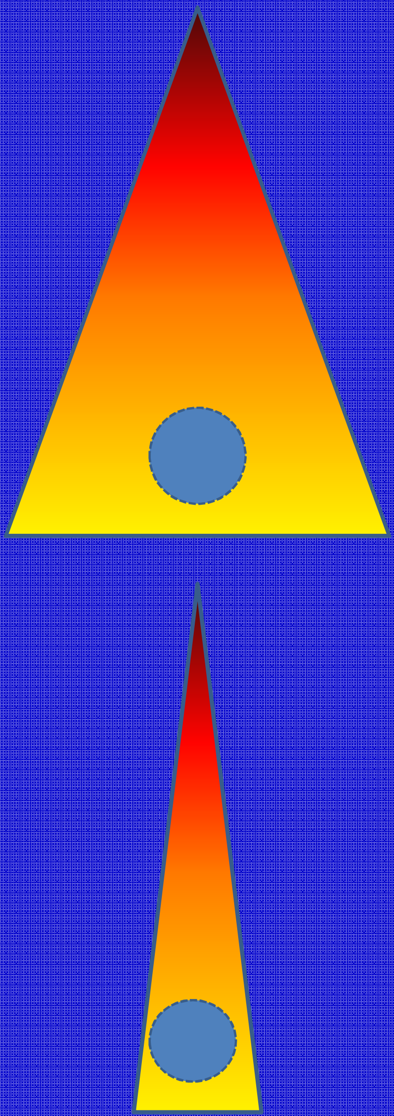
4-D Dose Calculation



Keall et al.: 4D radiotherapy planning ,Medical Physics, Vol. 32, No. 4, April 2005

Tumor Tracking



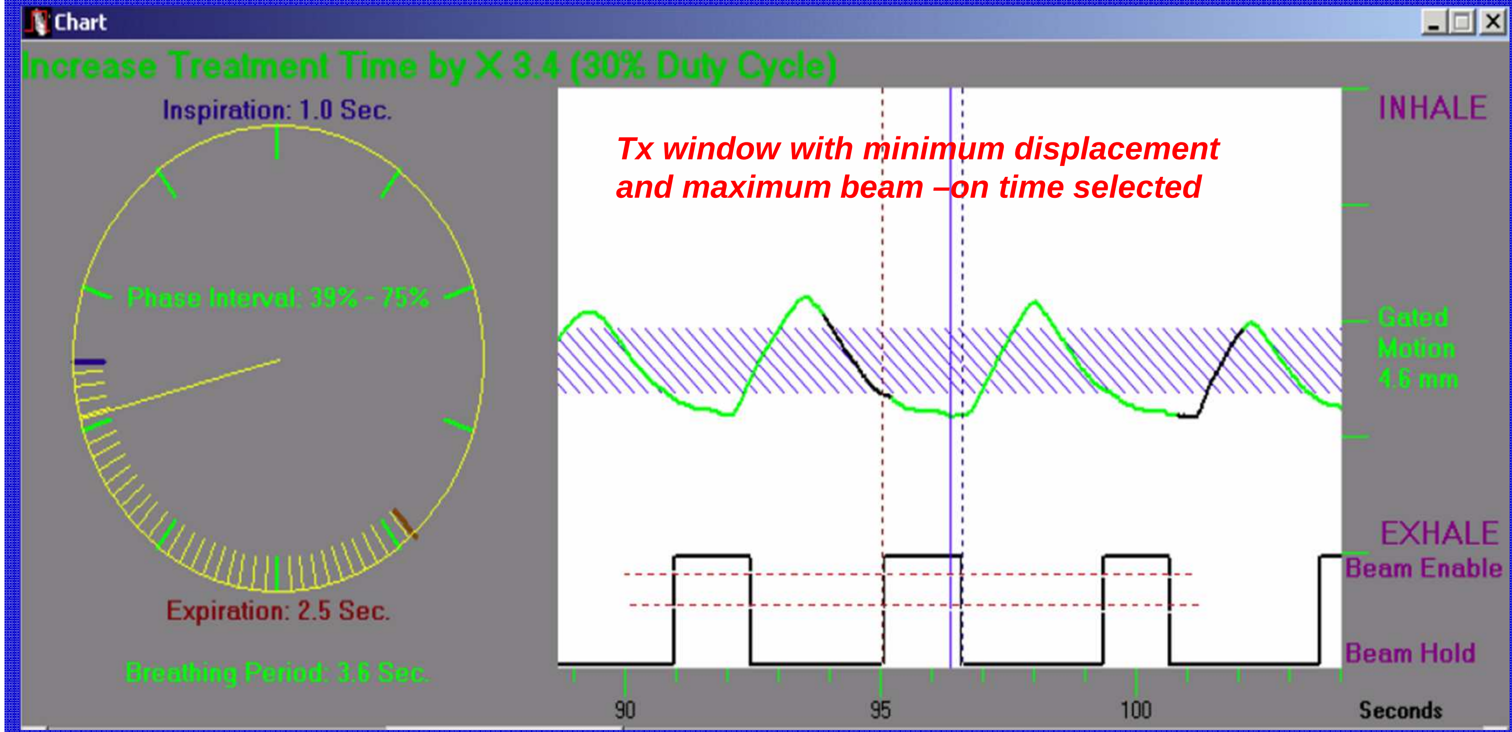


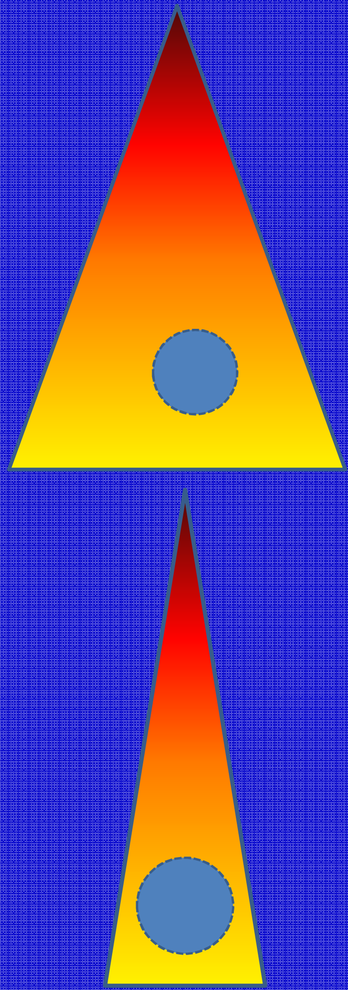
Gating

Treatment beam is turned on and off as tumor enters and exits a static treatment field

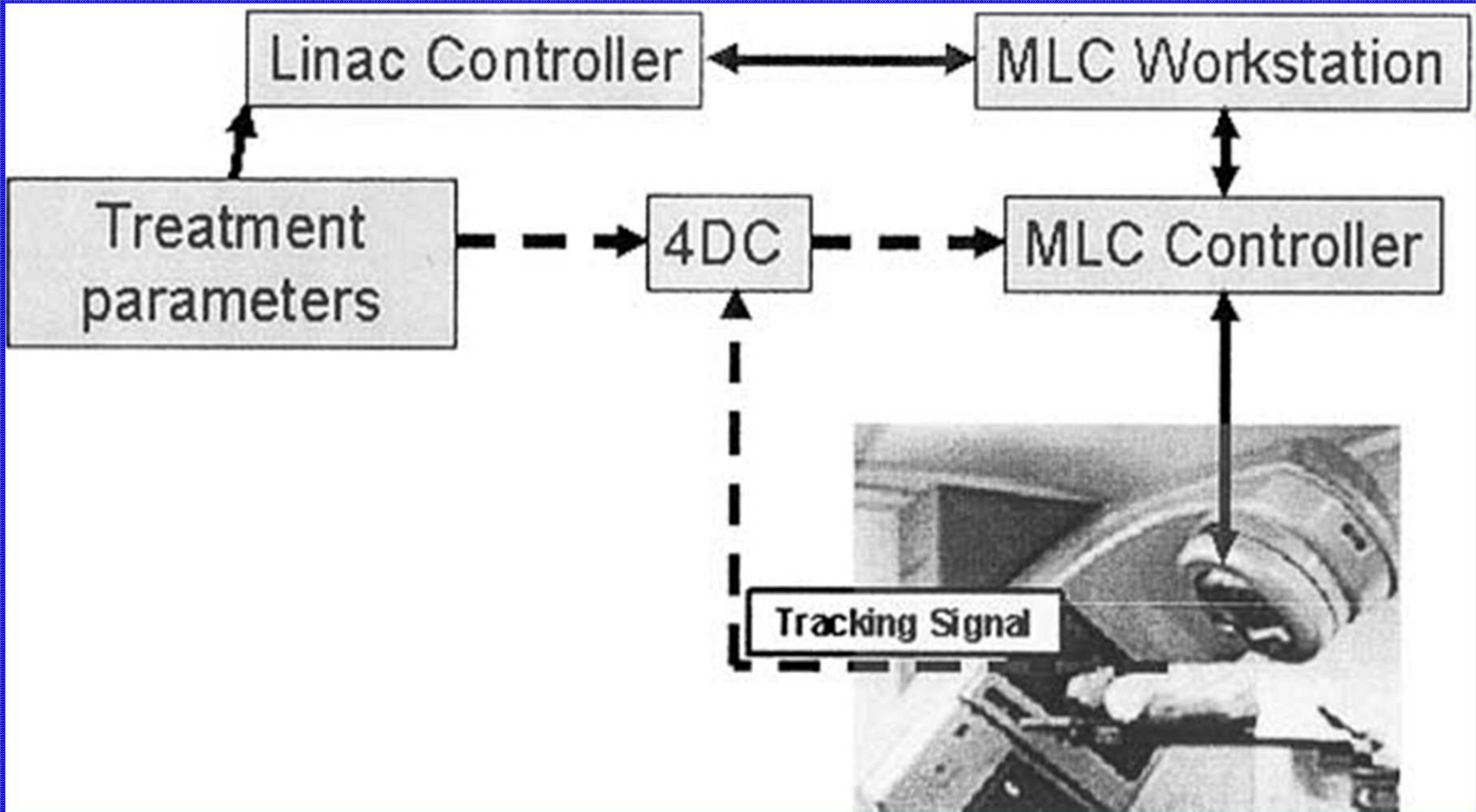
The ratio of the time spent by the signal within the gate to the overall treatment time is referred to as the duty cycle

Reduced margins increases therapeutic gain



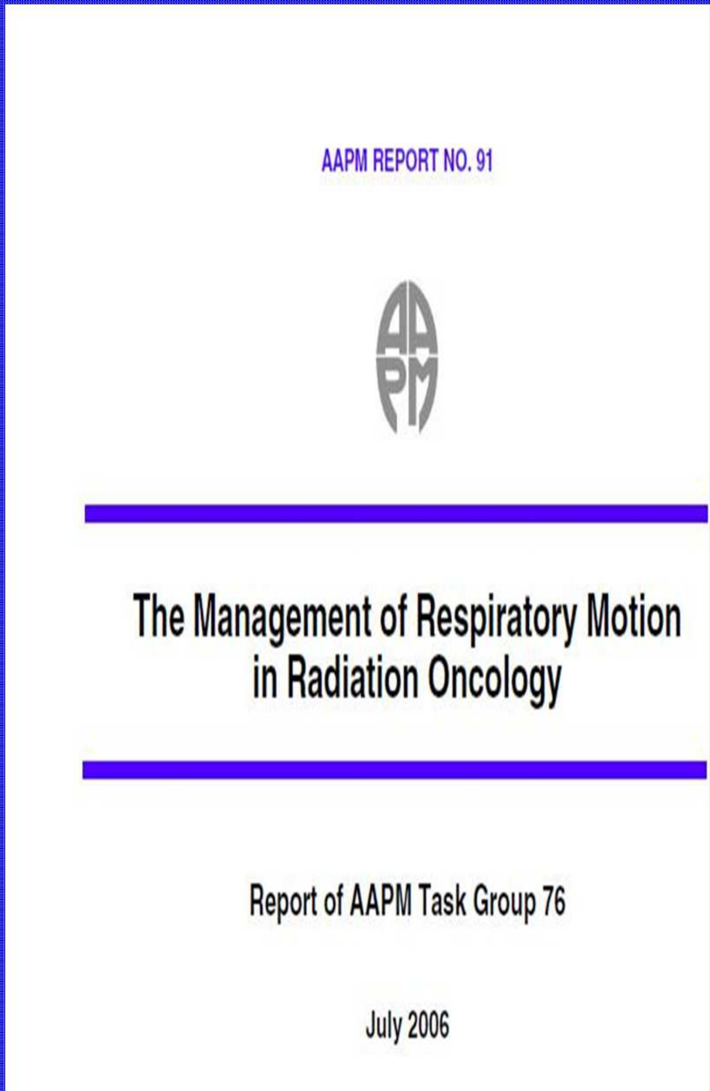


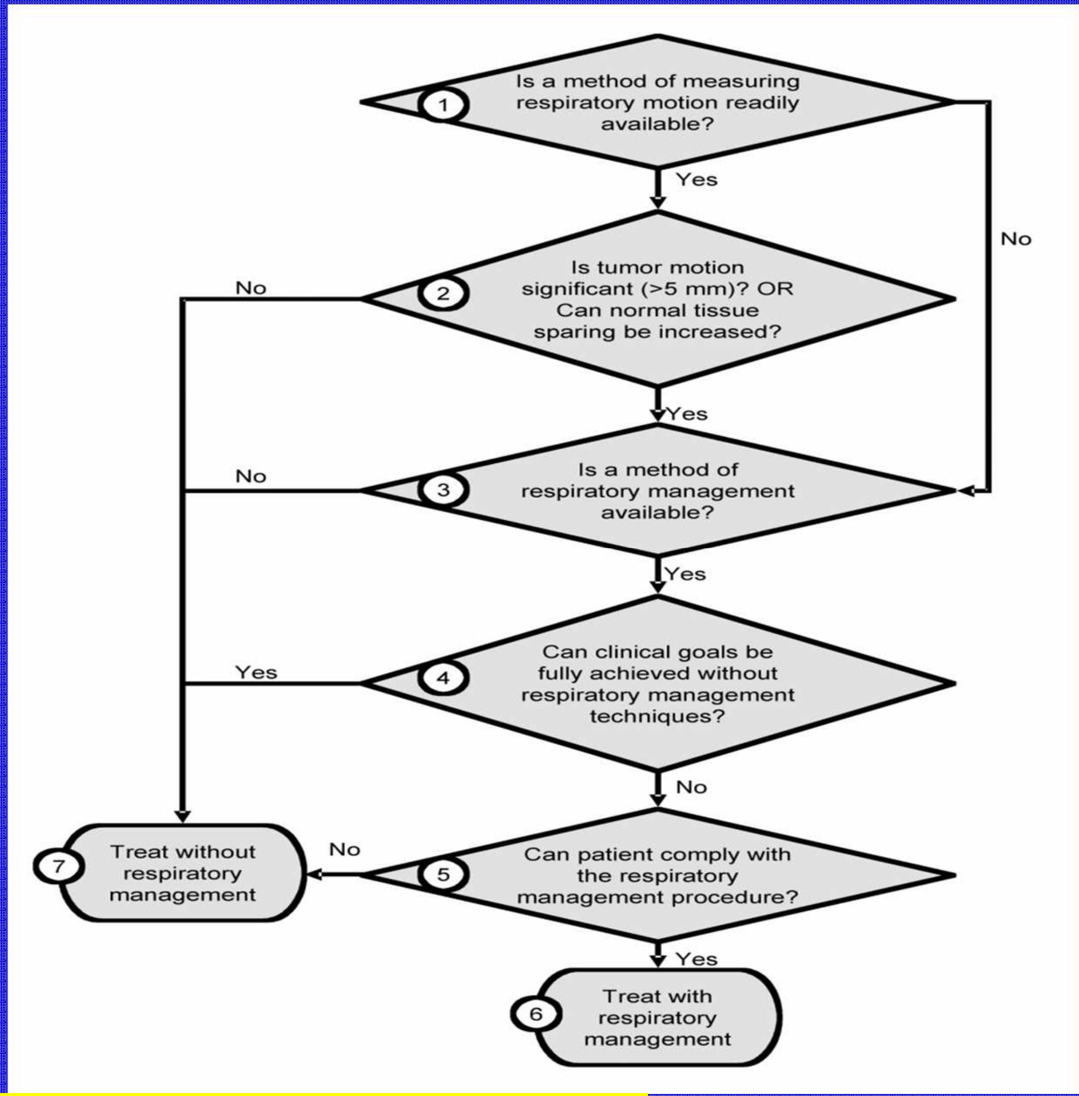
4-D Treatment delivery framework



Seminars in Radiation Oncology, Vol 14, No 1 (January), 2004: pp 81-90

When to use respiratory management techniques?





http://www.aapm.org/pubs/reports/RPT_91.pdf

Summary

- In 4-D radiotherapy the temporal anatomic changes are included in imaging, planning and delivery
- Limiting factor is the reproducibility of respiratory cycles during / in-between the treatment courses
- Linear accelerators should have predictive software and feedback system to deliver 4-D treatments
- Technologically more complicated
- QA methods are still evolving
- Potential to achieve higher therapeutic gain

Questions?

Thank you