# Image Guided Radiotherapy


**Dr. G. K. Rath**

Professor and Head of Radiotherapy &

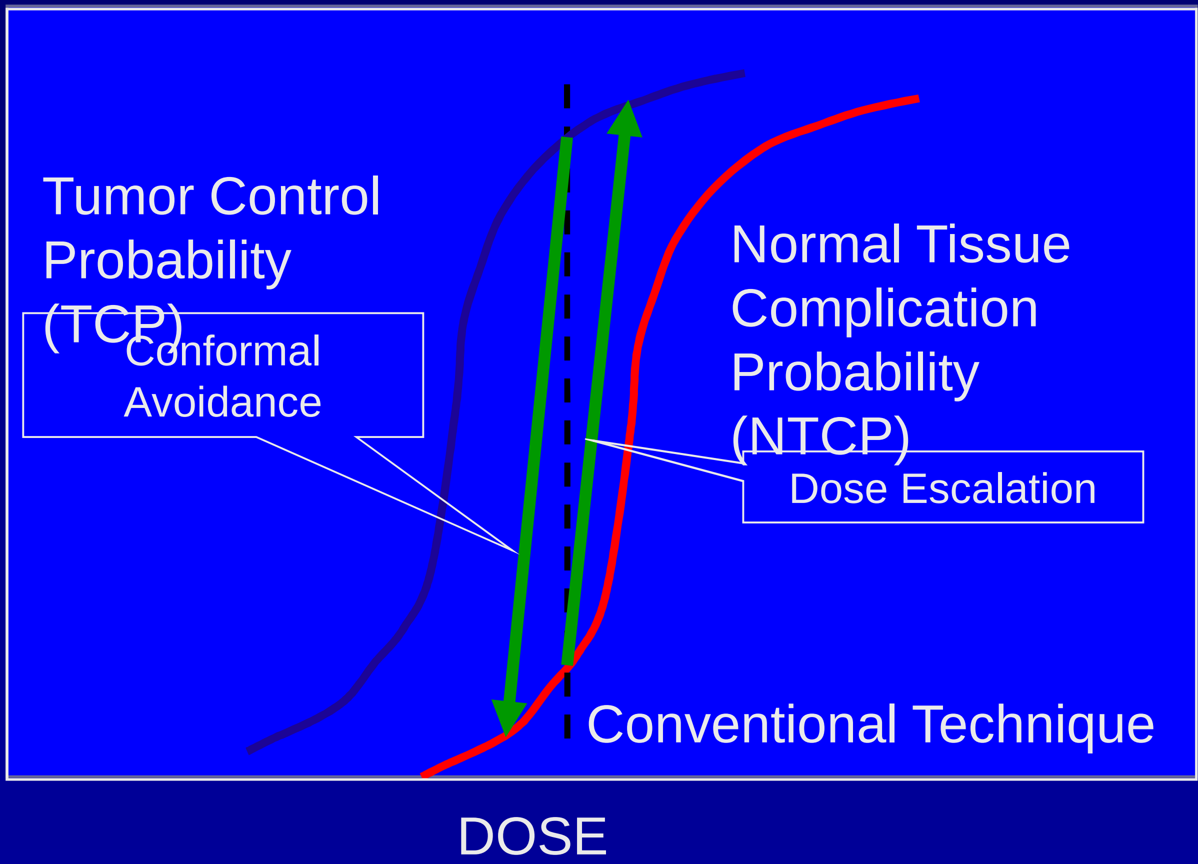
Chief, Dr. BRA IRCH,

All India Institute of Medical Sciences, New Delhi

# Treatment Planning - Goals

**Deliver maximum dose to the tumor (Increase cure rate)**

**Reduce dose to the surrounding normal structures (reduce complications)**



## Dose Escalation → Improved Results

- ***Ca Prostate***

- **The rate of positive biopsies decreased linearly as dose escalated (3DCRT)**

**81 Gy -7% pos biopsy rate,**

**75.6 Gy -48%,**

**70.2 Gy -45%,**

**64.8 Gy -57%**

***Zelefsky et al.*** Int. J. Radiation Oncology Biol. Phys. ***1998;41;491-500***

# Dose Escalation → Improved Results

MDACC 4 YR PSA free survival rates:

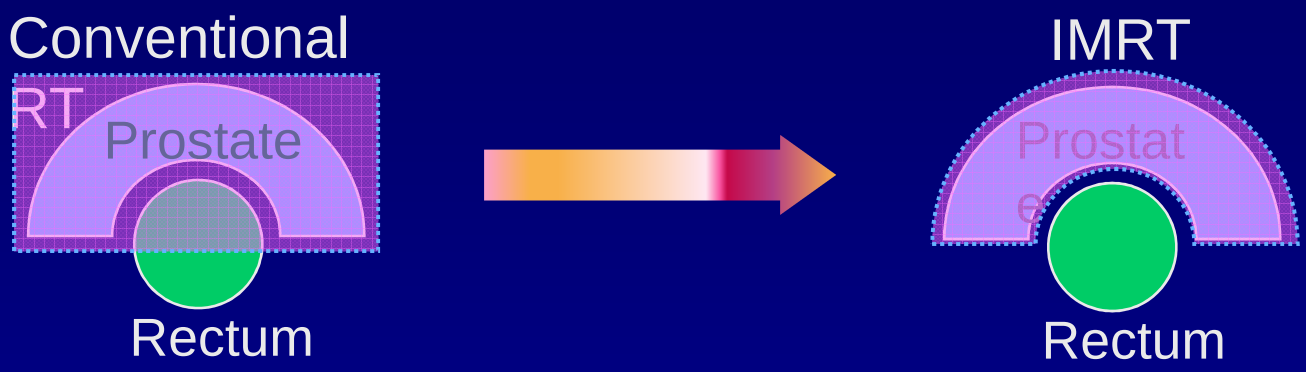
<67 Gy-(n=500)-54%

67-77 Gy-(n=495)-71%

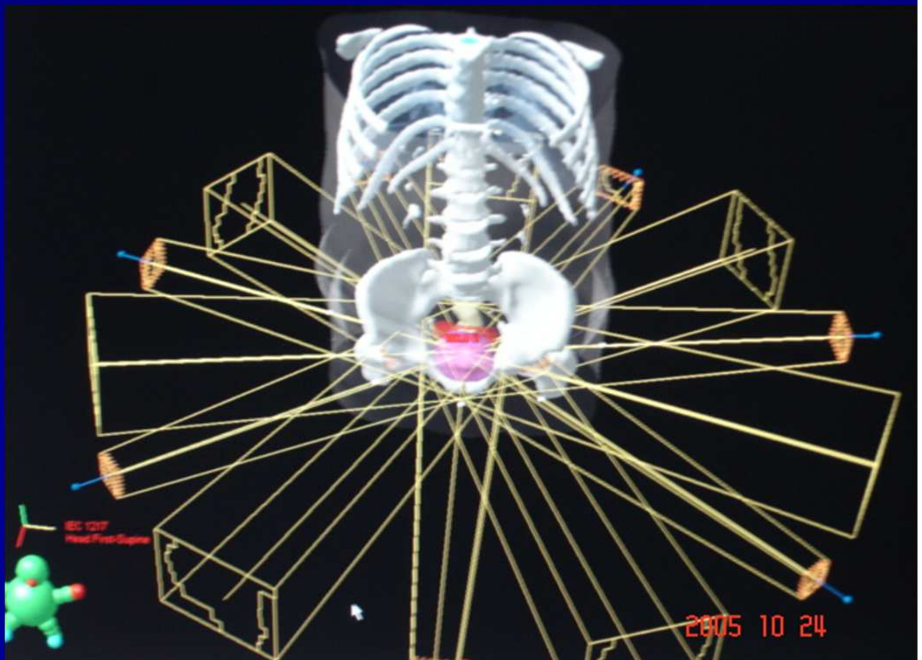
>77 Gy-(n=132)-77%

*Pollack et al. Int. J. Radiation Oncology Biol. Phys 1997;39;1011-18*

# IMRT Gives Improved Conformity




- Improved clinical outcomes
- Less complications and side effects
- More effective treatment
- Reduced need for invasive procedures



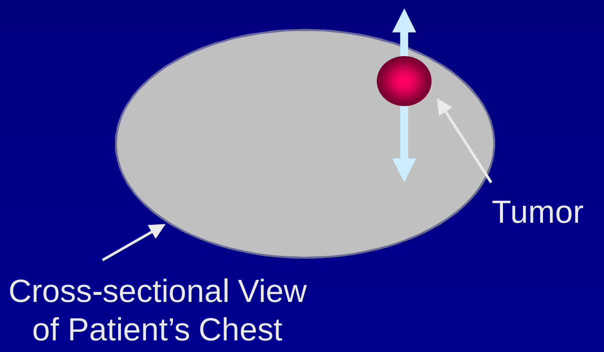
# Organ Motion is the CONCERN

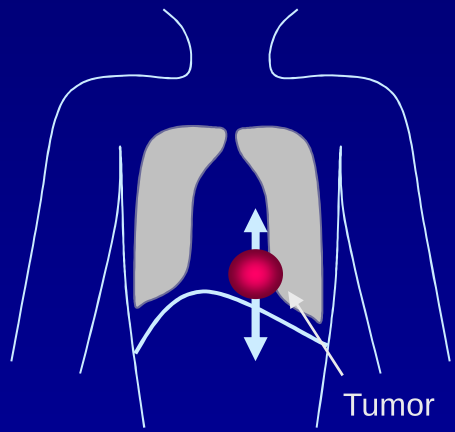
- **Interfraction**
  - **motion occurs between fractions and primarily is related to changes in patient localization**
- **Intrafraction**

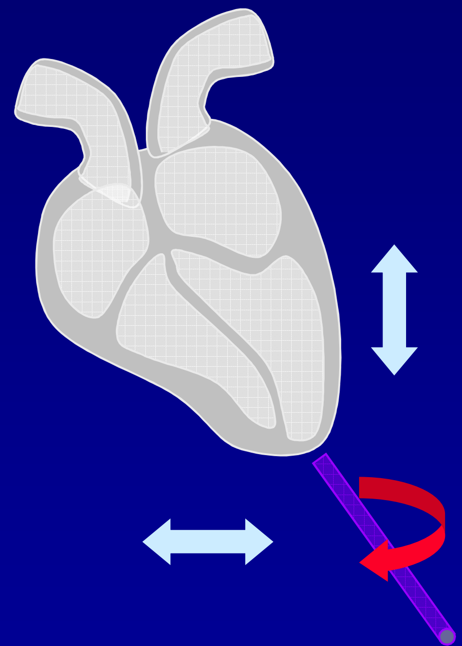
  **- motion occurs during fractions and primarily related to respiration**
- **Interfraction Deformation**

# Tumor Motion During Respiration

- All tumor motion is complex



Some motion is mostly Anterior / Posterior

Some motion is mostly Superior / Inferior

All tumor motion is Complex

# Tumor Motion: How Often?

**Table 1** Anatomic "Motions" and the Timescale at Which They Occur

| | | |
|---|---|---|
| Day to day | Skin motion | Nonpredictable |
| Hour to hour | Prostate motion | Nonpredictable |
| Minute to minute | Bladder filling | Predictable |
| | Neck flex | Nonpredictable |
| Second to second | Respiration | Predictable |
| | Heartbeat | Predictable |
| | Peristalsis | Nonpredictable |

Van Herk M. Semin Radiat Oncol 2007; 17: 258-267

# Factors influencing target localization and positioning

A. Patient motion

B. Weight loss

C. Absence or presence of fluid

D. Bone mineral losses

# Factors influencing target localization and positioning

E. Periodic physiologic movements

- Peristalsis
- Blood flow
- Breathing
- Cardiac motion

F. Random physiologic movement

- Swallowing
- Coughing
- Hiccups
- Sneezing

# Factors influencing target localization and positioning

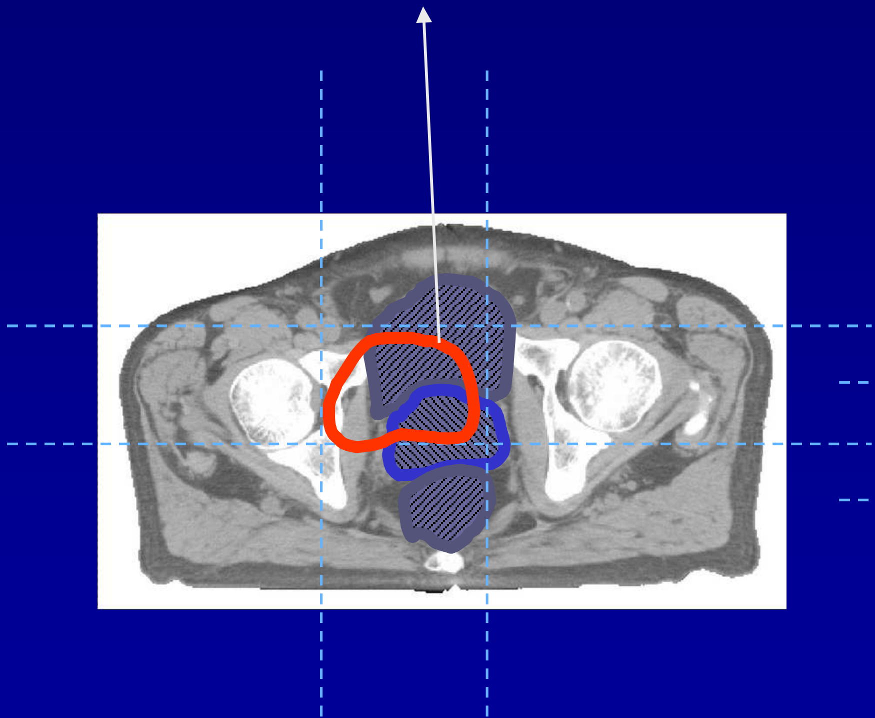
G. Transfer errors

H. Transpositional errors

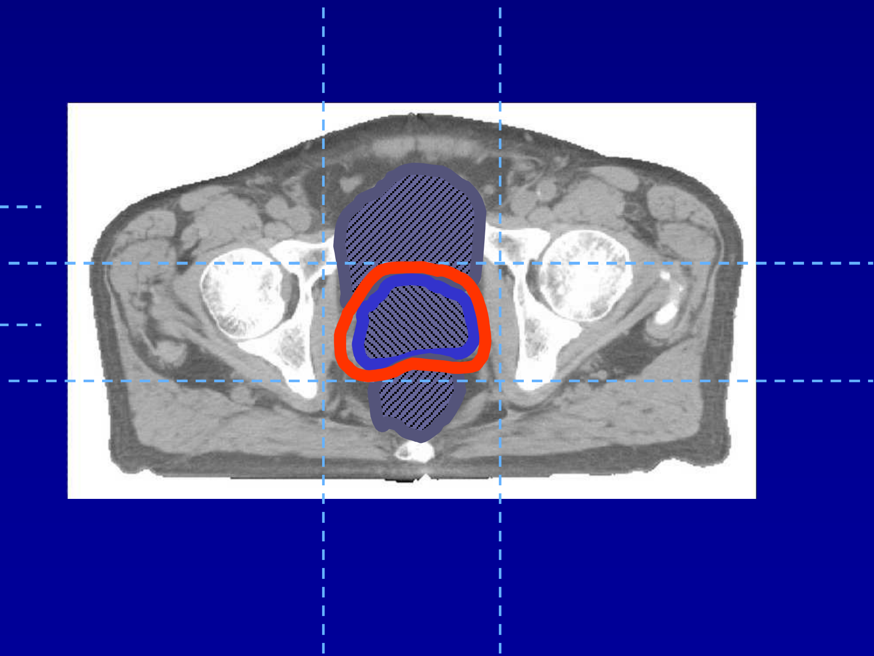
I. Setup errors (either initial or repeat)

# Efficient Treatment Also Requires Accuracy !!!

Radiation shaped to target but missing target



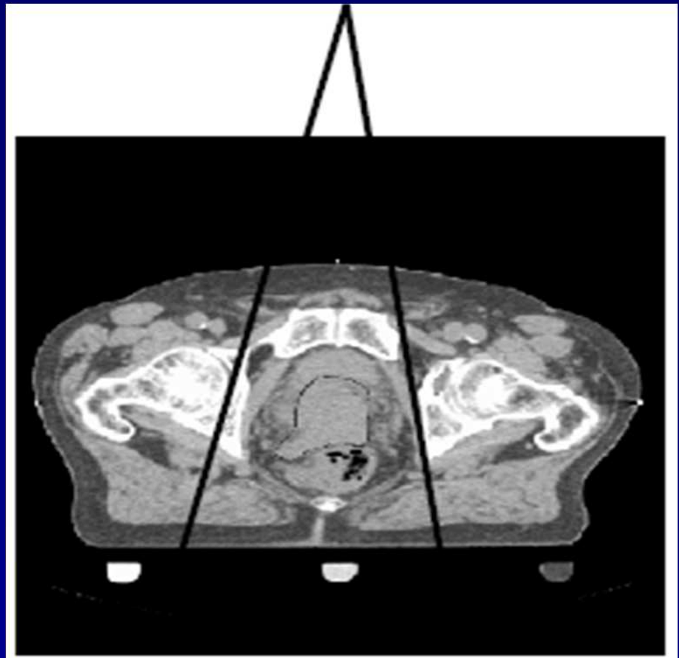
The right target



# CAUTION

*With tight margins being taken in highly conformal radiotherapy techniques there is a risk of precisely missing the target with organ motion.*

# To Combat These Uncertainties



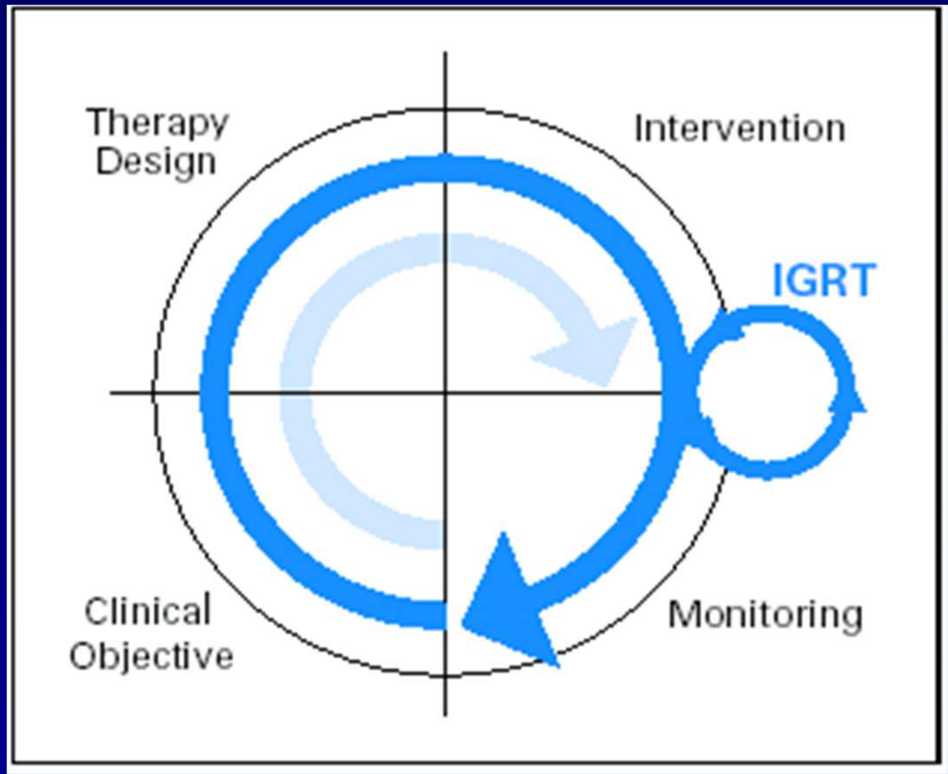
1. Use large margins, irradiating too much healthy tissues

volume = 4/3 ¶ $r^3$
a small reduction in margin (5mm)
yields a reduction by half in volume
*Verellen D,* Nature Reviews cancer
2007;7:949-61

Or

2. Use IGRT

# IGRT




Dawson LA et al. JCO 2007;25:938-46

IGRT is defined as frequent imaging in the treatment
room that allows treatment decisions to be made on the basis of these
images.

# Four- Dimensional Radiotherapy (4DRT)

- IGRT in which the localization accuracy– not only in space but also in time – is improved

- In comparison to that in 3DRT tumor position is monitored during the delivery of the therapeutic beam.

Shirato H, et al. Int J Clin Oncol 2007; 12:8–16

# History IGRT Technology


**1958- Holloway et.al reported portable x-ray machine mounted on the counter weight to TheratronCo-60 machine**

# Clinical Indication for IGRT

- Tumors adjacent to critical structures
- Tumors prone to inter fractional motion
- Tumors prone to intra fractional motion
- Tumors prone to deformation
- IMRT, SRS/SRT/SBRT
- Hypofractionation schemes

# IGRT Tumor Sites

- Ca lung
- Ca Prostate
- Head and Neck
- Ca Rectum
- Ca Cervix

# IGRT : Available Options

IGRT encompasses the following present day Technology

- Volumetric

  CT on rails

  Tomotherapy

  MV cone beam CT

  KV cone beam CT

- Planar X ray based

  EPID

  Cyber knife

- Video based

  Real Time video guided IMRT

- Ultrasound based

  BAT

# Current IGRT in Market

| Ultrasound | Video-Based | Planar: X-Ray | Volumetric |
|---|---|---|---|
| BAT | Video Subtraction | EPID | In-Room CT |
| SonArray | Photogrammetry | CyberKnife | FOCAL, MSKCC |
| I-Beam | AlignRT | Novalis | CT-on-Rails |
| Restitu | Real-Time Video | RTRT | Primation |
| | | Gantry-Mounted Prototype | Varian ExaCT |
| | | Tohoku | Tomotherapy |
| | | IRIS Commercial | MV Cone Beam CT |
| | | Varian OBI | Siemens |
| | | Elekta Synergy | kV Cone Beam CT |
| | | | Mobile C-arm |
| | | | Varian OBI |
| | | | Elekta Synergy |
| | | | Siemens In-Line |

**Related Technologies**

RPM gating/4DCT

Optical-guided Approaches

# Techniques of Tumor Tracking

- Skin Markers

  Not adequate for IGRT as margins required for uncertainty will be 1.5 –2cm

- Internal markers

  A. CT based Bony Anatomy tracking

  B. CT based Soft Tissue Tracking

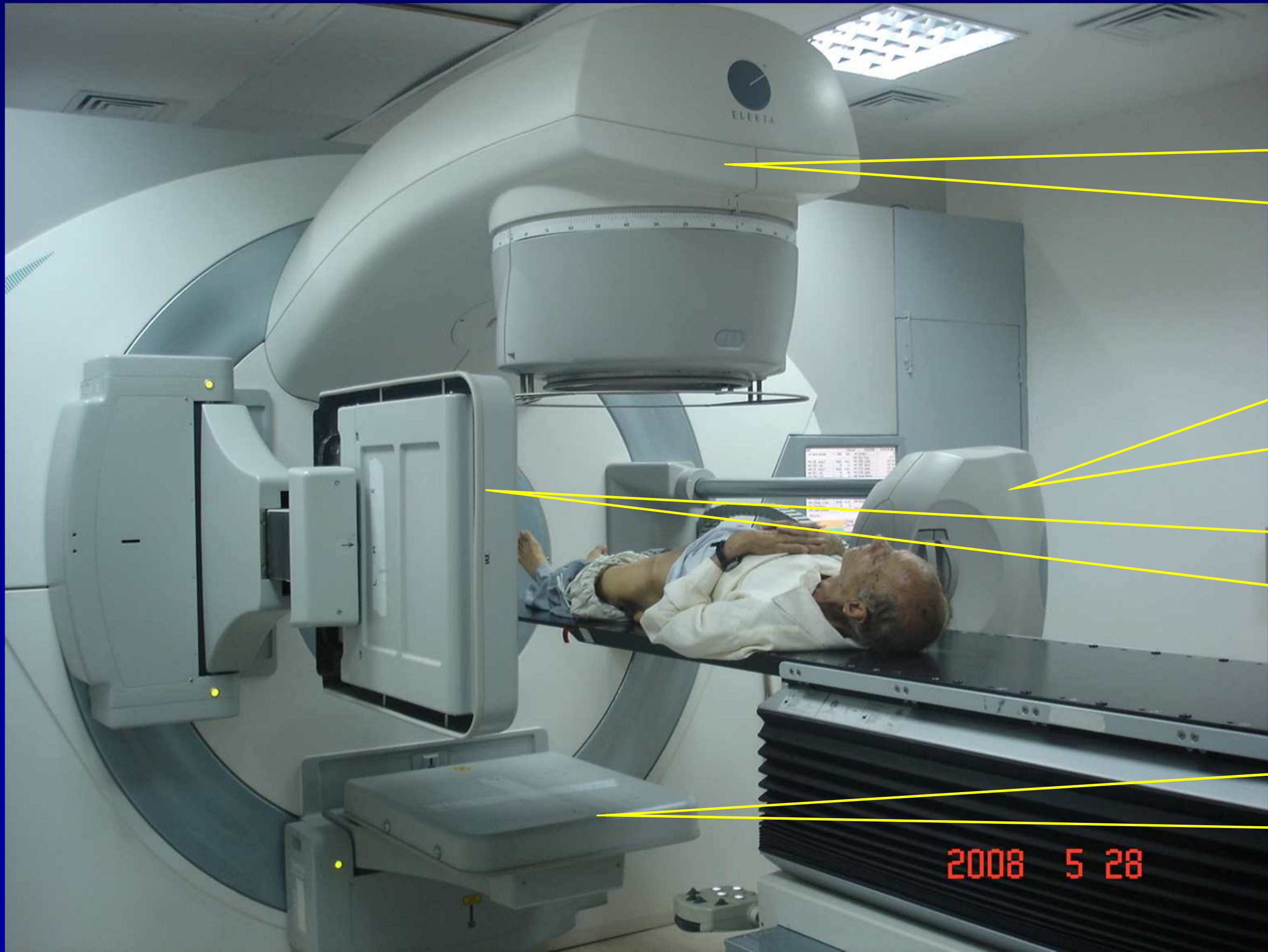
  C. Implanted fiducials
  (Deformation is a problem, Less inter user variation, Good stability)

  D. Implanted radiofrequency transponders for electromagnetic tracking
  (miniature Global Positioning Systems)

  E. Endo-rectal balloon
  (can reduce rectal radiation dose, Renders rectal dosimetry more predictable by making rectal anatomy more reproducible)

# CT in the treatment room

# IGRT at AIIMS




Megavoltage radiation source

Kilovoltage radiation source

Kilovoltage imager

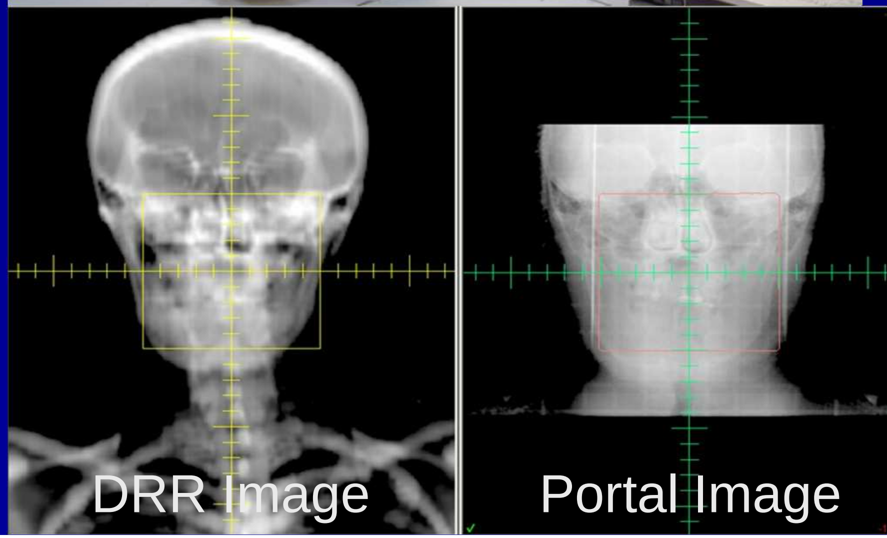
Megavoltage imager

# Electronic portal imaging (EPID)

Uses 6 MV beam to acquire image. require one AP and one LAT field for setup verification

The position error is determined using the rigid body registration between a daily treatment radiographic image and a reference radiographic image digital reconstructed radiographic (DRR) image created in treatment planning

Uses bony anatomy or implanted radio-markers position as a surrogate to verify patient setup position



# Electronic portal imaging (EPID)

**Pros**

- Mount on the linear accelerator
- Treatment beam to acquire image
- Real time imaging
- Beams eye view verification
- Low dose (2cGy-3cGy)
- Setup accuracy < 2mm

**Cons**

- Very low contrast due to the high energy of the photons
- matching can only be two-dimensional
- Tissue information is lacking
- Patient Rotational error correction not possible

# 3D Volumetric Imaging

- 3-D volumetric imaging inside a treatment room
- true 3-D information can be acquired with a CT scanner in the same room just before the start of treatment
- allows for more accurate guidance to setup the patient's position relative to the treatment beams
- In-room CT images used to reconstruct dose distributions
- allows image-guided adaptive radiotherapy

# Tomotherapy : Helical MVCT

- Dedicated IGRT/IMRT treatment uni
- MVCT imaging
- Translational correction only

Pros

- MV CT devices offer an advantage when scanning patients with hip prostheses or dental fillings because the high Z material does not produce an artifact at megavoltage energies
- Large field of view (FOV) of 40 cm

Cons

- Use of MV treatment beam for imaging may force compromises between the dose delivered and the image quality
- Patient throughput is less

# Megavoltage cone-beam CT (MV-CBCT)

Flat-panel detectors based EPID mounted on a linac gantry and the therapy MV x-ray

Possible to acquire multiple, low-dose 2-D projection images

<u>Advantage</u>

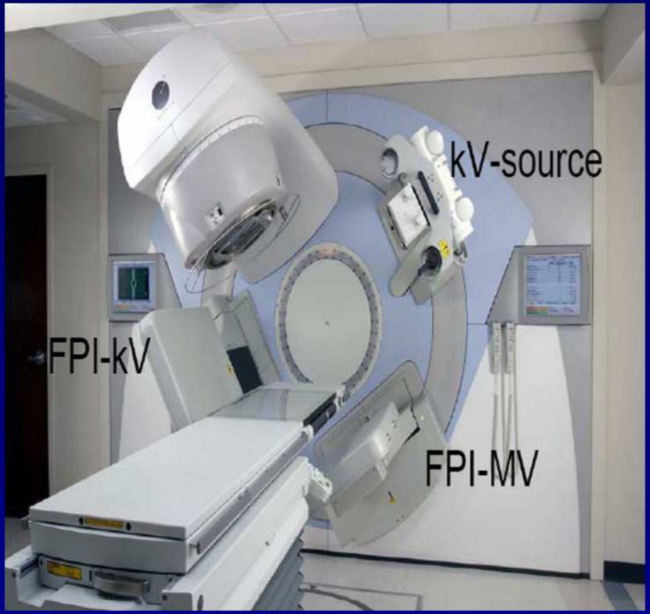
- it does not require the extensive modification of a Linac
- CBCT imaging system uses a large detector and a single rotation

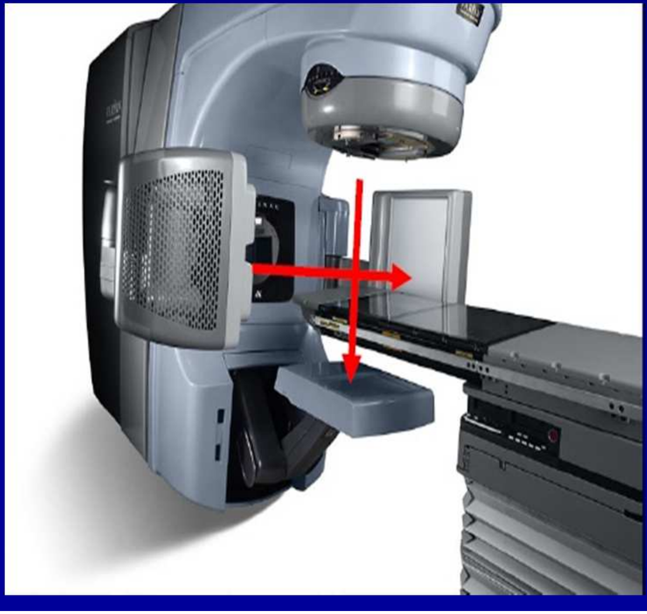
<u>Disadvantage</u>

- lack of discrimination of soft tissue and bony objects by the physics of high-energy x-rays

# kV-CB CT On-board imager

- Radiography, fluoroscopy, and CBCT
- Large flat-panel imager
- kV x-ray tube mounted on a retractable arm at 90 degrees to the treatment beam line
- Cone-beam CT reconstruction acquiring multiple kV radiographs as the gantry rotates through at least 180 degrees



**Advantages**

- real-time information is available
- No surrogates required

**Disadvantages**

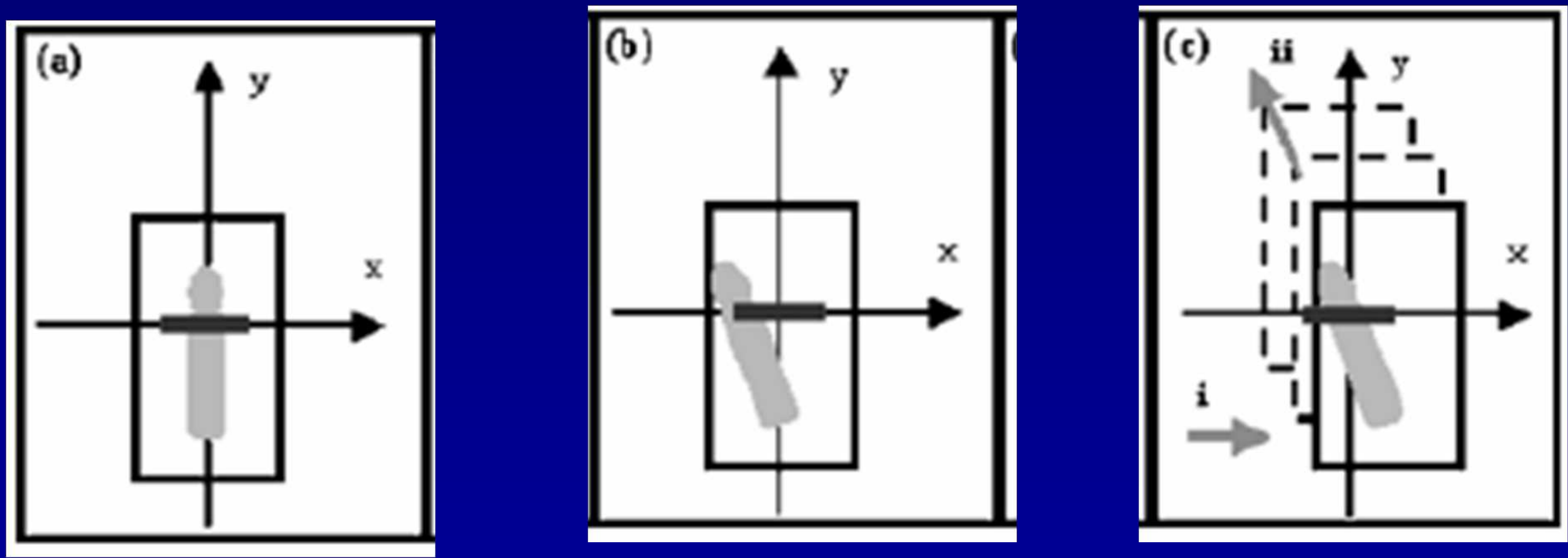
- Mechanically less stable
- Requires careful calibration

# How to Correct for Displacements

- Couch corrections
- Gantry and collimator angle adjustments
- Modification of multi-leaf collimator leaf positions

# Couch Corrections

Correction by lateral couch shift (Tomotherapy)




*Boswell et al. Med Phys. 2005; 32:1630-9.*

# Hexapod Couch at AIIMS



# 6 Degrees of Freedom






# Non-Radiographic techniques: Ultrasound

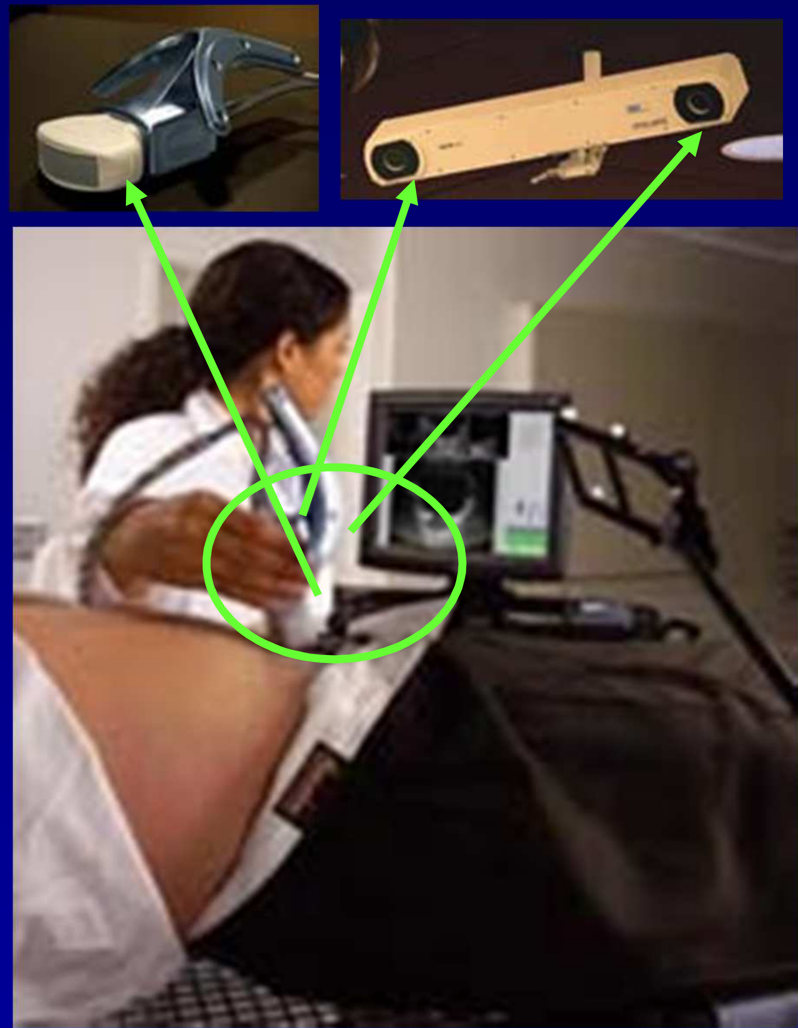
- Noninvasive
- No radiographic
- Relatively easy imaging

<u>Advantages</u>

- No surrogate required (soft tissue visualization)
- Remaining random error same magnitude as with initial set-up

<u>Disadvantages</u>

- CT-contour ≠US-structure
- Important inter-user variability



# **Electromagnetic Field Tracking:** Calypso system

- Electromagnetic fields to induce and detect signals from implanted wireless devices

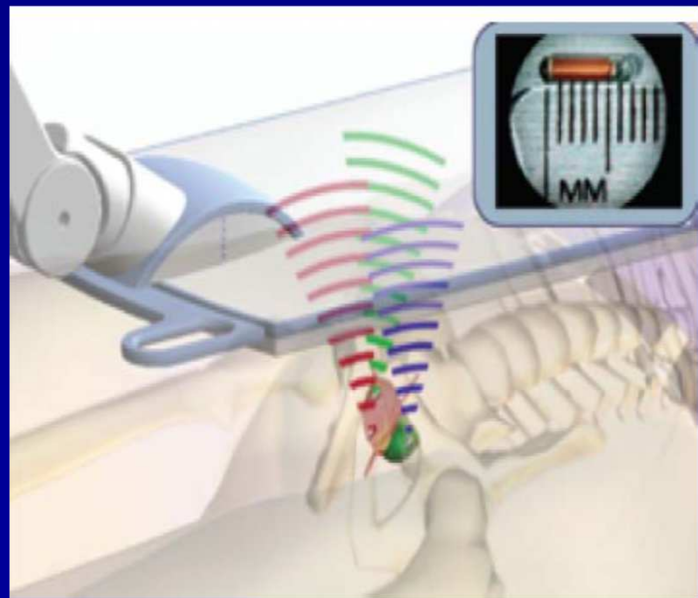
- System consists of a console optical tracking system and a tracking station

- The magnetic array is lightweight and contains the source coils which generate signals to excite the transponders, and the sensor coils which detect the unique response signals returned by each transponder

- Can actively detect the position of transponder without using the radiographic method

- The Calypso 4-D Localization system can update target position ten times per second, fast enough to track breathing motion of the tumor

- Sub millimeter tracking accuracy



# Methods to account for Respiratory motion

- Motion encompassing methods
- Respiratory Gating methods
- Breath-hold methods
- Forced shallow breathing with abdominal compression
- Respiratory tracking methods

# Motion encompassing methods

(i) Slow CT scanning

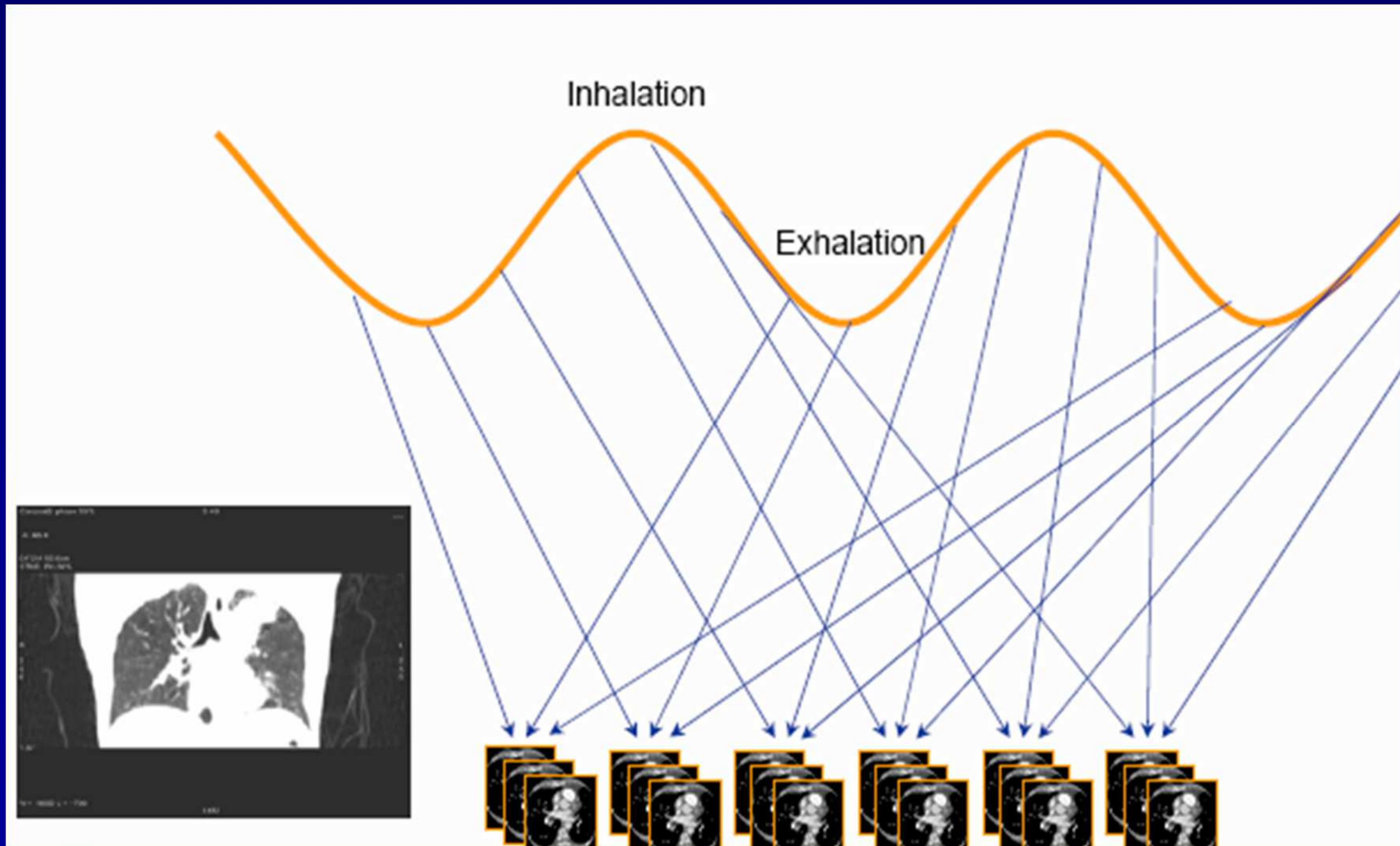
(ii) Gated/breath hold CT

Prospective respiratory correlation

(iii) 4DCT

Retrospective respiratory correlation

# Principle of 4D scanning



# Different between 3D and 4D CT

| Process/Setup | 3D | 4D |
|---|---|---|
| Scan – light breathing | Acquire ~ 100 slices 1 volumetric study | Acquire 1500+slices – multiple volumetric studies |
| Dose | ~ 1 cGy | 3-5 Time greater dose |
| Reconstruction | Conventional | Conventional followed by resorting/multiple sets OR projection sorting followed by conventional reconstruction |
| 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 shape and trajectory; create composite ITV |
| Generate DDRs | Conventional | At specific phase of pseudo fluoroscopic DRR movie loop |
| Image guided patient set up | Standard guidance by bony anatomy of clips | Guidance by gated of multiple image acquisitions (compare DRRs) |

# Respiratory Gating

- Radiation delivery synchronized with the respiratory signal
- A reflective marker block is placed on the patient to detect respiration motion (or internal fiducial markers)
- Marker blocks are illuminated by infrared emitting diodes
- Software tracks the position of the marker

# Respiration Gating with RPM

- RPM is a external gating system
- System consists of an infra-red camera that is mounted to the foot of the CT
- Markers block containing 2 reflectors.
- The marker block was placed on the patient's skin in the abdominal region
- Surrogate signal = abdominal surface motion correlation to tumor motion
- The x-ray on signal from the CT scanner was recorded synchronously with the respiration signal

Real-time position Management system (RPM)

Video Camera

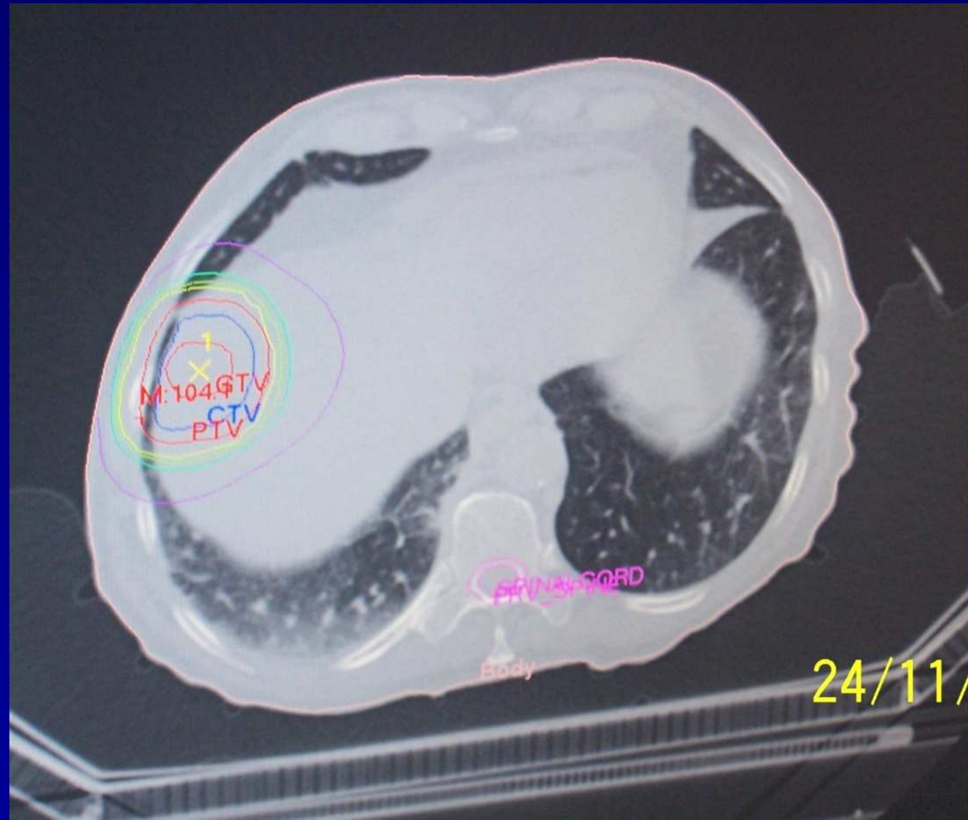
# Active Breathing Control (ABC)

- Temporarily immobilizes patient's breathing
- The inspiration and expiration paths of airflow are closed at a predetermined flow direction

# SBRT : Liver

# SBRT : Liver


Treatment Type: STATIC ARCS
Optimization Mode: None
Calculation Mode: NORMAL - Loaded
#18
#1
#2
#17
#16
#4
#15
#14
#13
#12
#11
#10
#9
#8
Computing Arc # 6
Beam # 3
Break

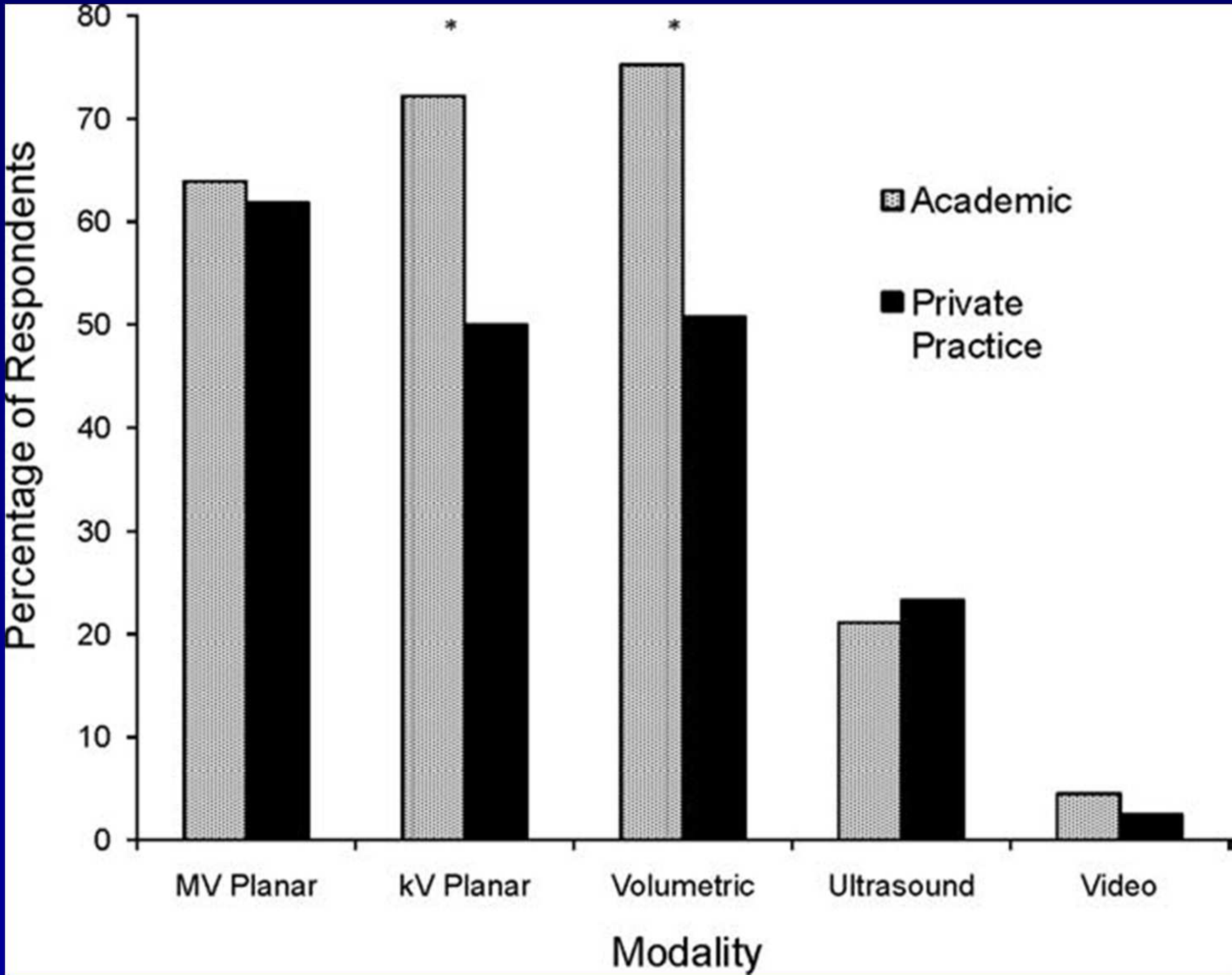

GTV
CTV
PTV
Body
24/11/

# A Survey of IGRT Use in the United States

- Of 1089 evaluable respondents, 393 responses (36.1%).
- Radiation oncologists using IGRT : 93.5%.
- The percentages using ultrasound, video, MV-planar, KV-planar, and volumetric technologies were 22.3%, 3.2%, 62.7%, 57.7%, and 58.8%, respectively.
- Among IGRT users, the most common disease sites treated were genitourinary (91.1%), head and neck (74.2%), central nervous system (71.9%), and lung (66.9%).
- Overall, 59.1% of IGRT users planned to increase use, and 71.4% of nonusers planned to adopt IGRT in the future

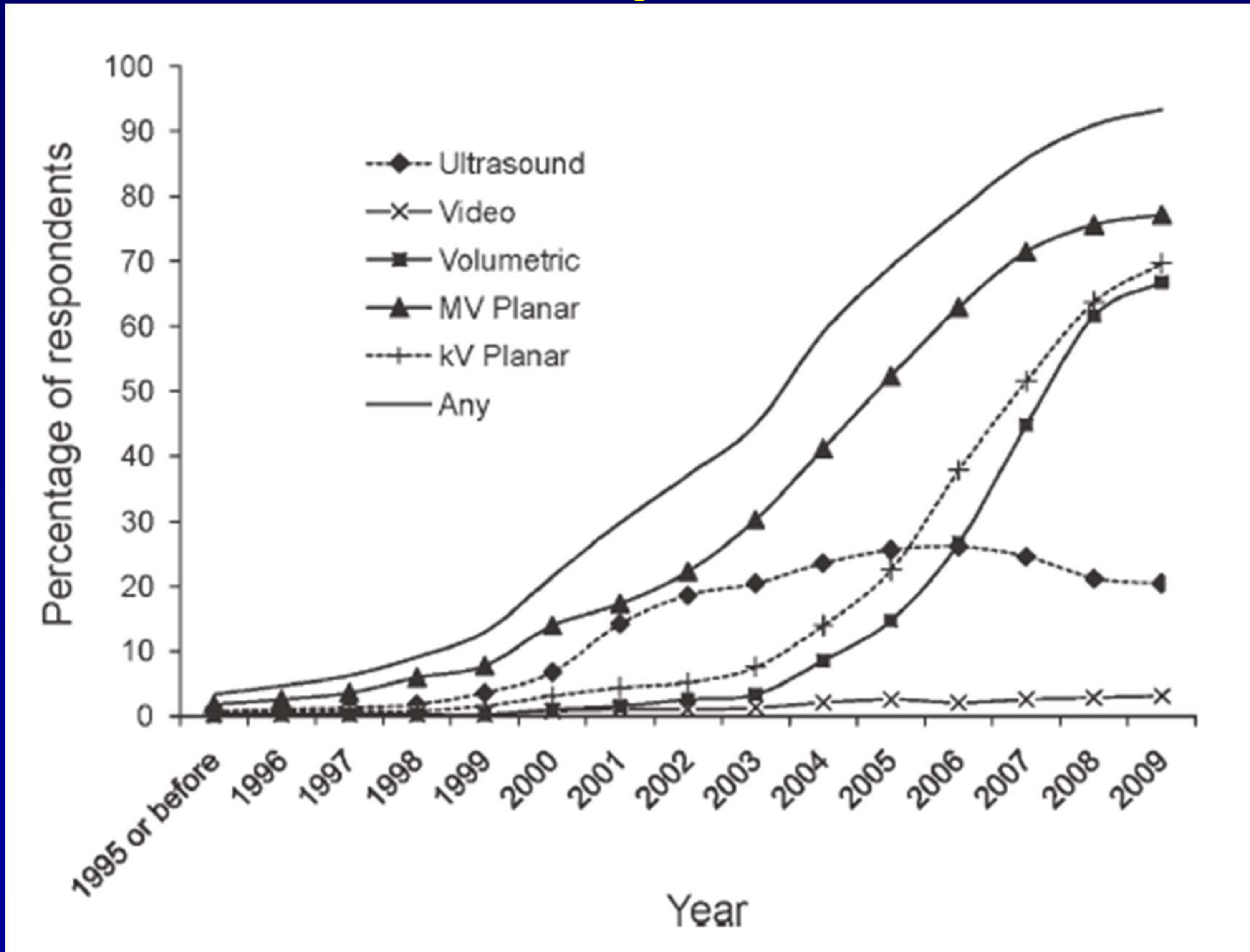
Simpson DR. Cancer 2010;116:3953–60.

# Academic vs. private-practice using IGRT technologies (asterisks, P < .05)




Simpson DR. Cancer 2010;116:3953–60.

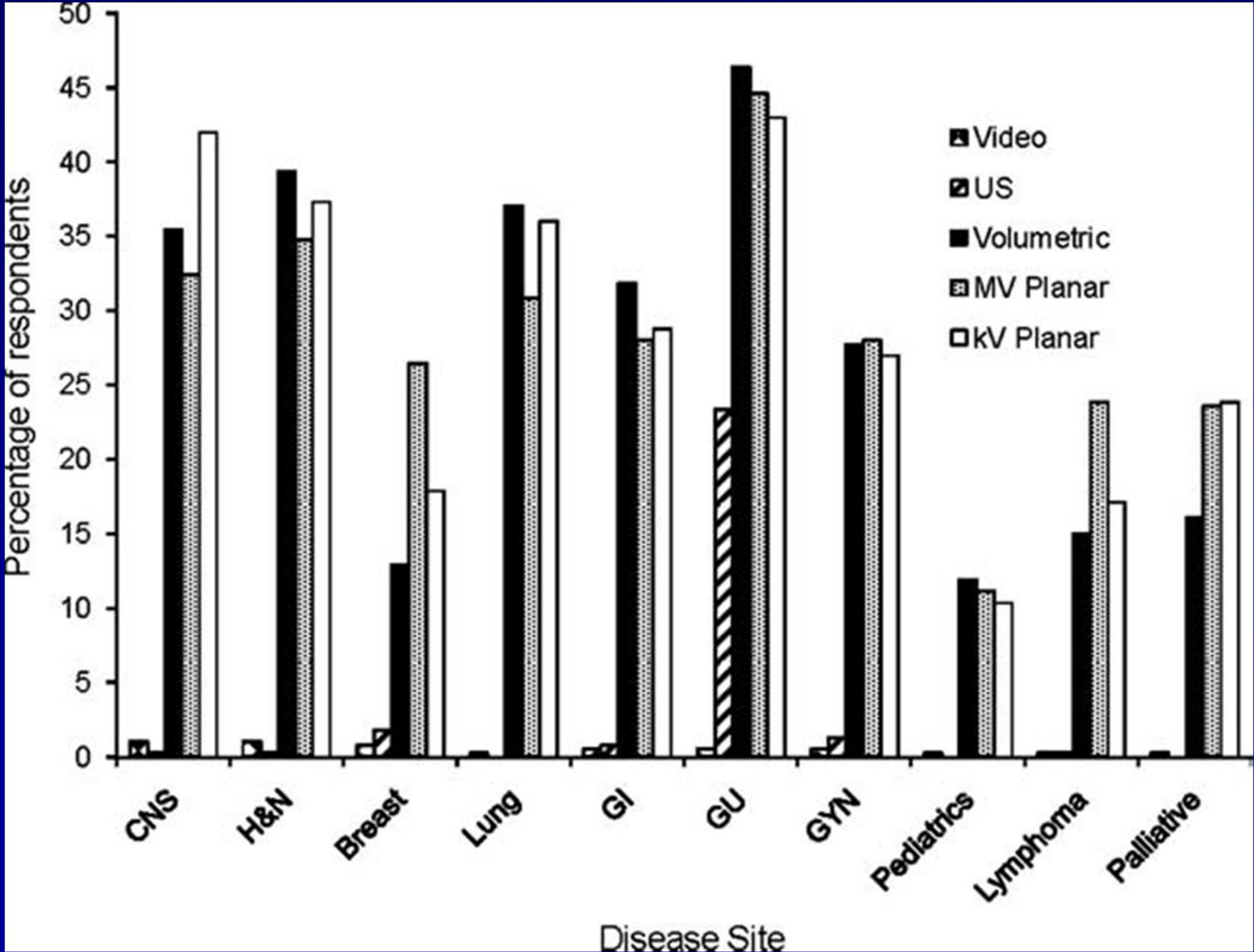
# Cumulative adoption of IGRT technologies Over Years






Simpson DR. Cancer 2010;116:3953–60.

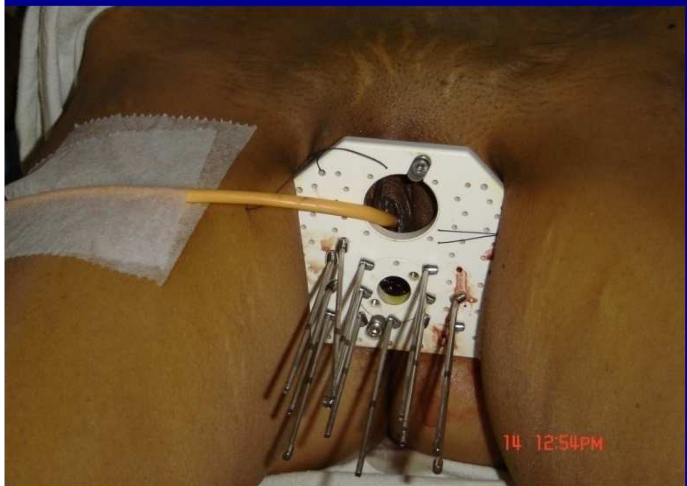
# IGRT Modalities by Disease Site

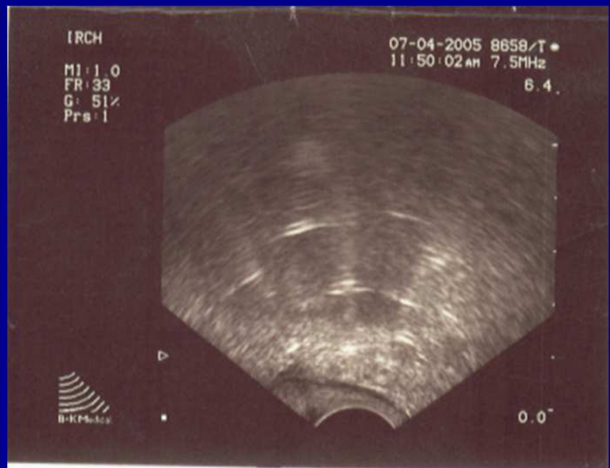



Simpson DR. Cancer 2010;116:3953–60.

# Image Guided Brachytherapy: Cervix


TRUS Probe

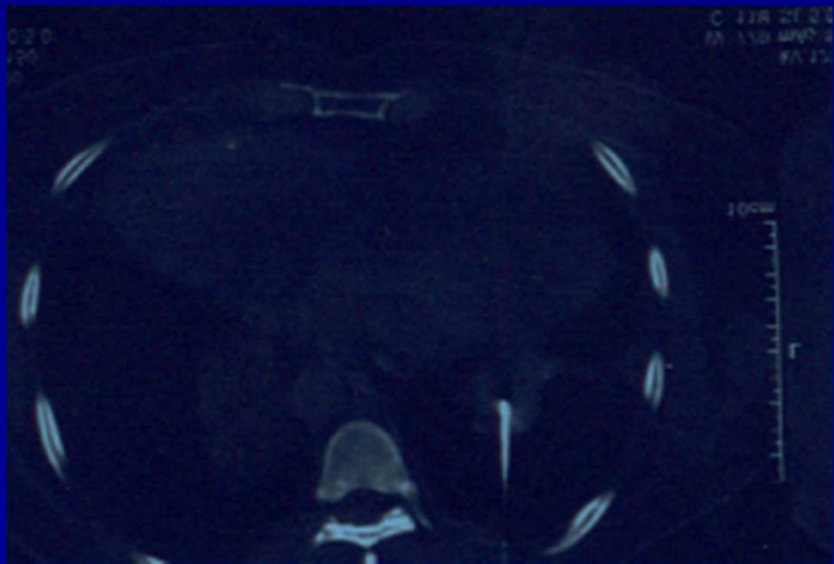




# Dose reduction to normal structures

| | Rectal dose (of Pt A) | Bladder dose (of Pt A) |
|---|---|---|
| ICRT | 60-70% | 70-80% |
| Interstitial | 20-25% | 20-25% |

# Image Guided Brachytherapy: Lung



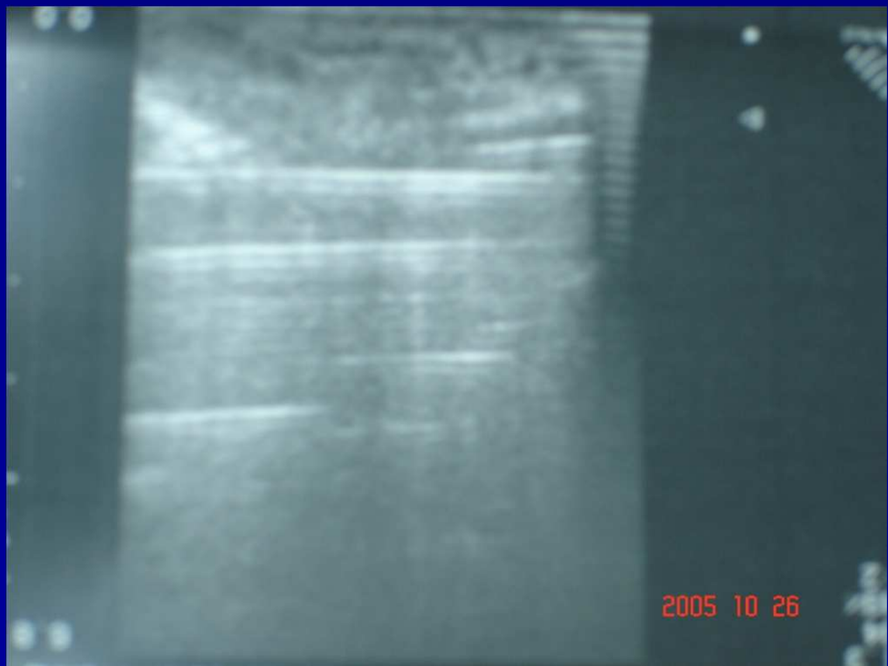


# Image Guided Brachytherapy: Prostate





2005 10 26

2005 10 26

2005 10 26

2005 10 26

# Conclusion

- Ultimate objective of radiotherapy treatment is

  Increase tumor control probability

  Decrease normal tissue complications

- Has been difficult so far due to

  Target geometry uncertainty

  Intra-fraction and inter-fraction motion

# Conclusion

## The goal is possible …..

- Advances in imaging and modern RT facilities
- IGRT provides a solution for combating organ motion in radiotherapy
- Delivering higher dose to tumor and less dose to normal tissue.
- IGRT provides a natural quality-assurance step for conformal radiotherapy
- Image is better than imagination, but an image is always different from the real.
- Limited clinical studies, needs to be studied further

# Thank You