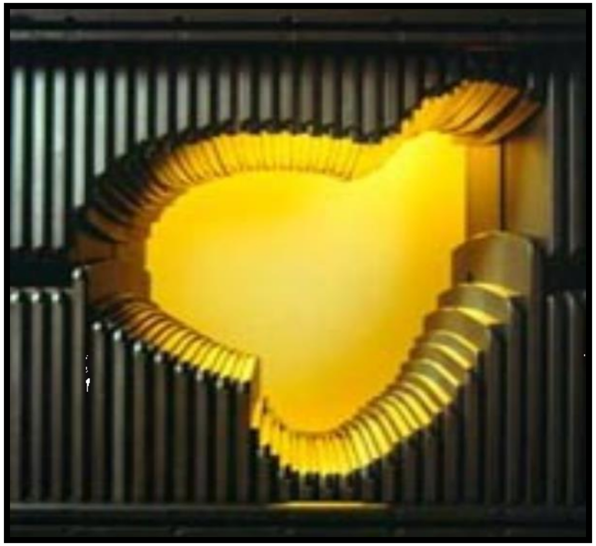
Conformal Radiation Techniques - An Evolution



Dr Pooja Nandwani Patel

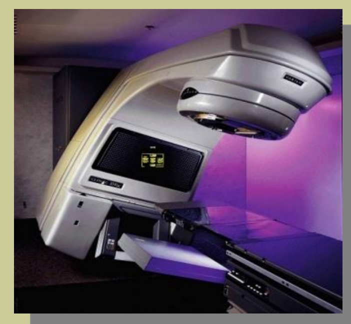
Sr. Consultant & Head

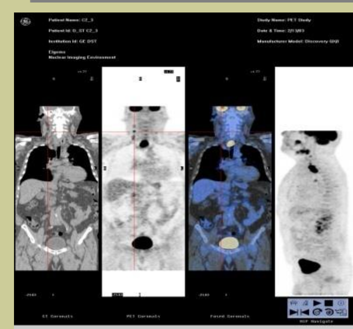
Dept. of Radiation Oncology

Sterling Cancer Hospital, Ahmedabad

The Evolution of Radiation Therapy

2000s



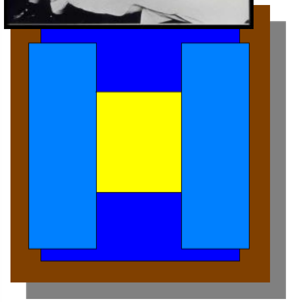


High-Resolution IMRT

The Evolution of Radiation Therapy

1960's

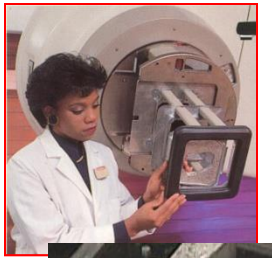
The First Clinac

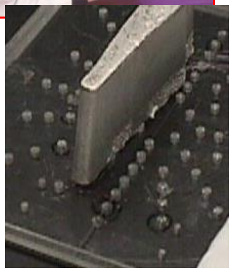


Standard Collimator

The linac reduced complications compared to Co60

1970's

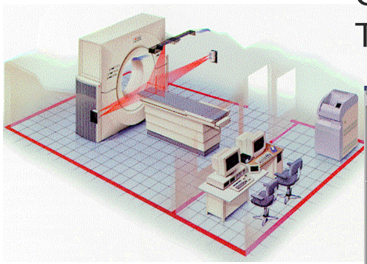




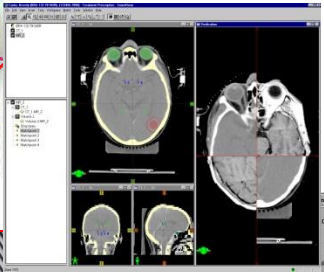
Cerrobend Blocking
Electron Blocking

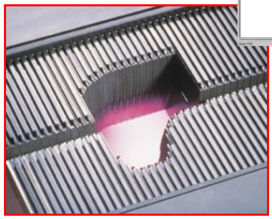
Blocks were used to reduce the dose to normal tissues

1980's



Computerized 3D CT Treatment Planning

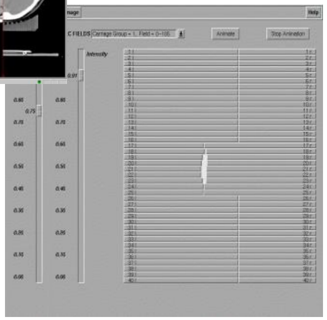




Multileaf Collimator

MLC leads to 3D conformal therapy which allows the first dose escalation trials.

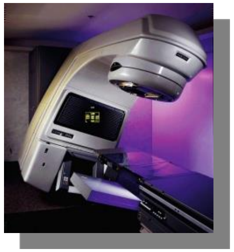
1990's

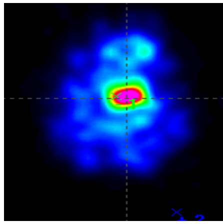


Dynamic MLC and IMRT

Computerized IMRT introduced which allowed escalation of dose and reduced compilations

2000





Functional Imaging

High resolution IMRT

IMRT Evolution evolves to smaller and smaller subfields and high resolution IMRT along with the introduction of new imaging technologies

EVOLUTION OF RADIOTHERAPY

2D (pre 1990)

- Conventional Square/Rectangle
- Parallel Opposing
- Deep X-Ray / Cobalt-60

3D (post1990)

- Blocks, Multileaf Collimator
- Conformal RT,
- SRS/SRT, IMRT

4D (Today)

- Motion and Time Real Time with Feedback
- IGRT, Cyberknife Tomotherapy

WHY ???

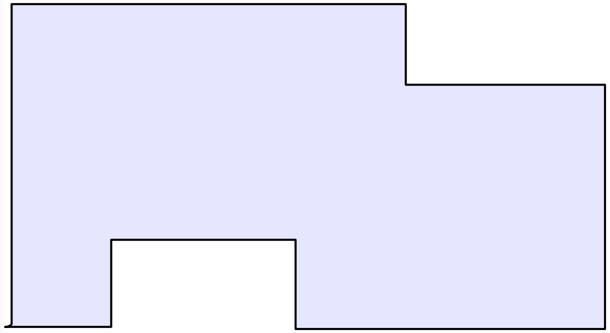
Accurate Treatment Delivery

High Tech Radiotherapy Machines

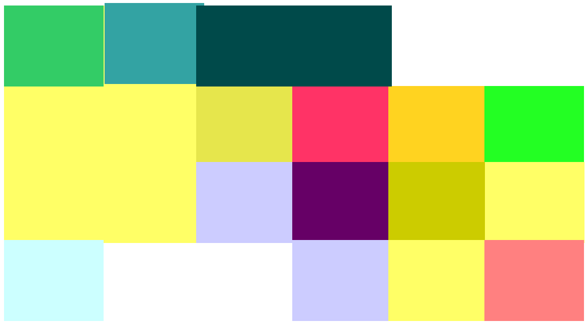
High Energy Linear Accelerator

Helical Tomotherapy

Types of Conformal Radiation



Geometrical Field shaping

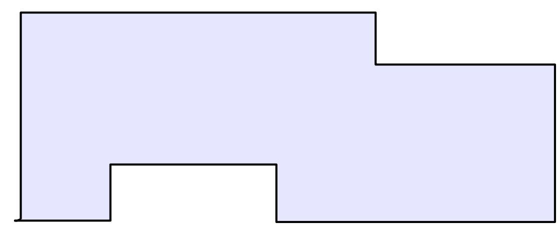


Geometrical Field shaping with Intesity Modulation

WHAT IS 3-D CRT

To plan & deliver treatment based on 3D anatomic information. such that resultant dose distribution conforms to the target volume closely in terms of

- Adequate dose to tumor &
- Minimum dose to normal tissues.



The 3D CRT plans generally

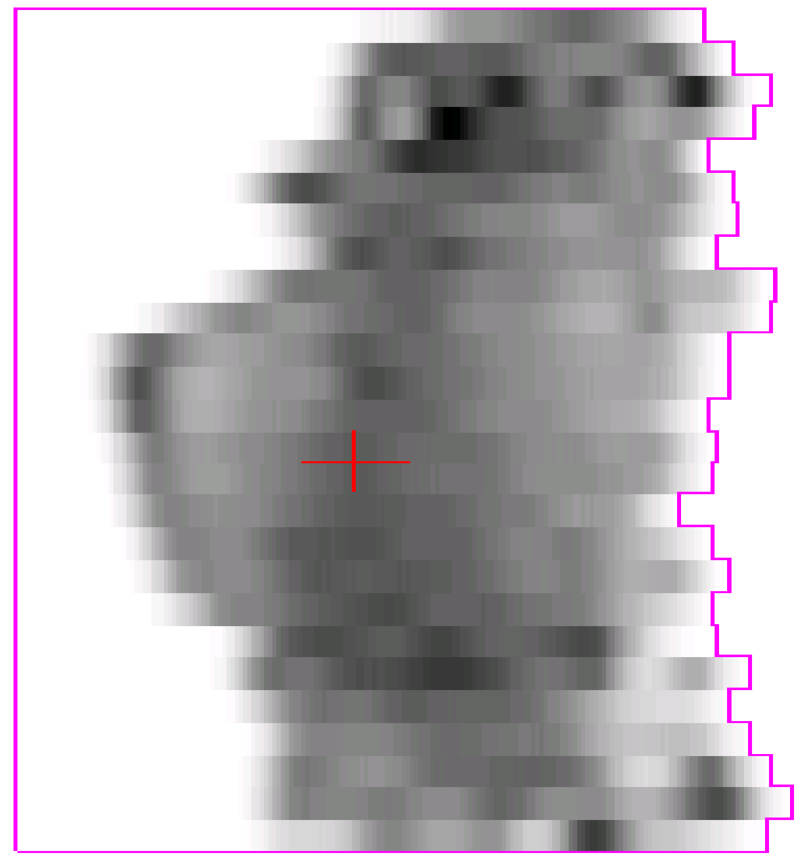
use increased number of radiation beams

to improve dose conformation and conventional beam modifiers (e.g., wedges and/or compensating filters) are used.

Intensity Modulated Radiation Therapy

- In its purest sense IMRT is intensity modulation.
- The ability to create customized intensity patterns
- It is “an advanced form of 3D-CRT that uses non-uniform radiation beam intensities” *

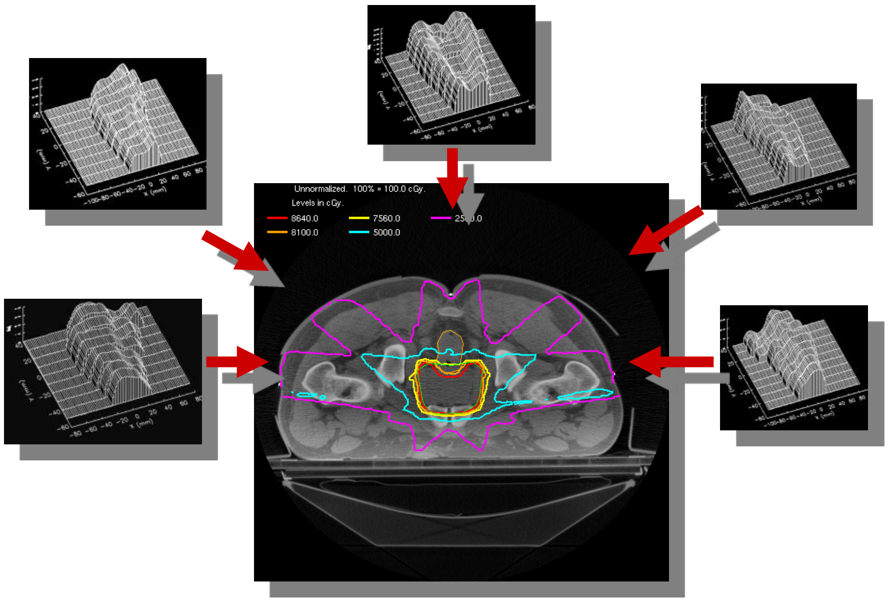
**Int J Radiation Oncology Biology Physics vol.51, No. 4 pp.880-914, 2001*



IMRT Intensity or Fluence Map

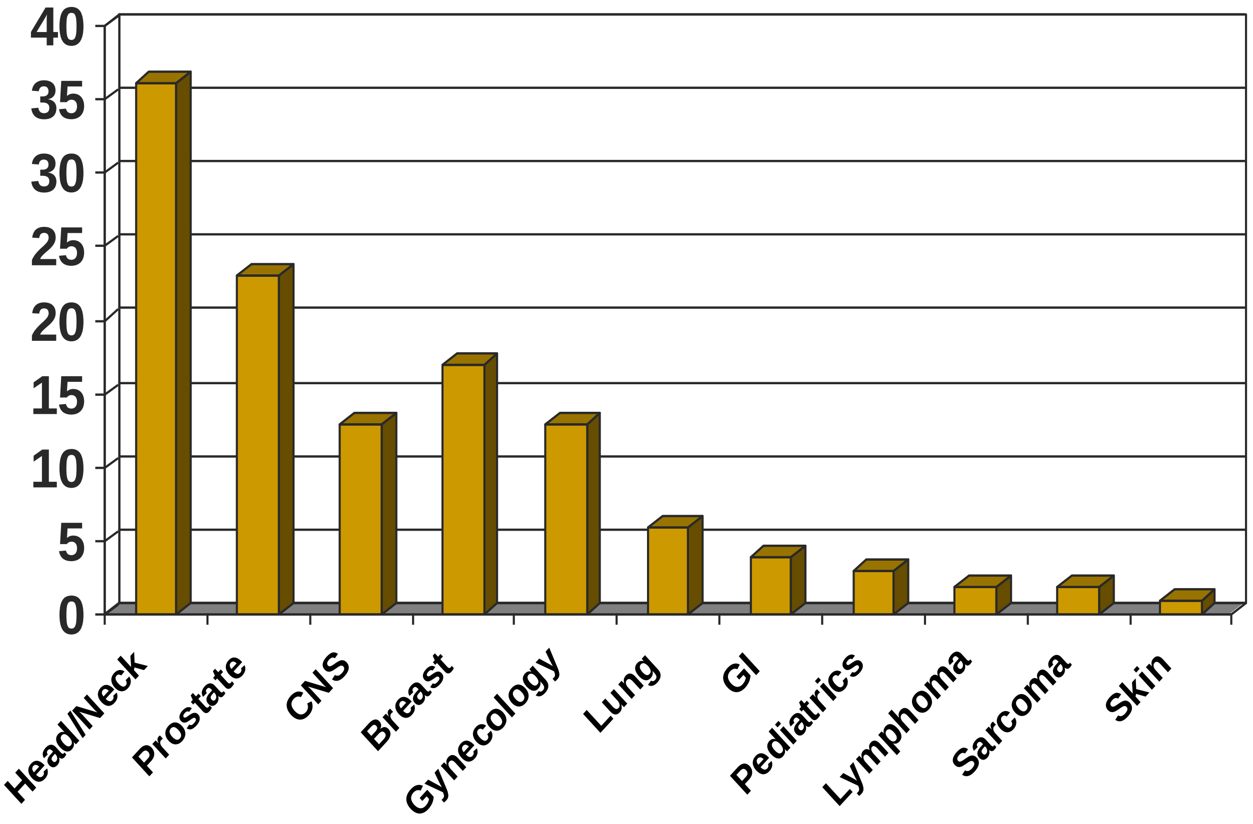
Intensity-Modulated Radiation Therapy

- IMRT is a process
  - Planning
  - Information Transfer
  - Delivery
  - Verification



- IMRT allows you to customize your treatment delivery based on a specific planning objective

IMRT Clinical Studies

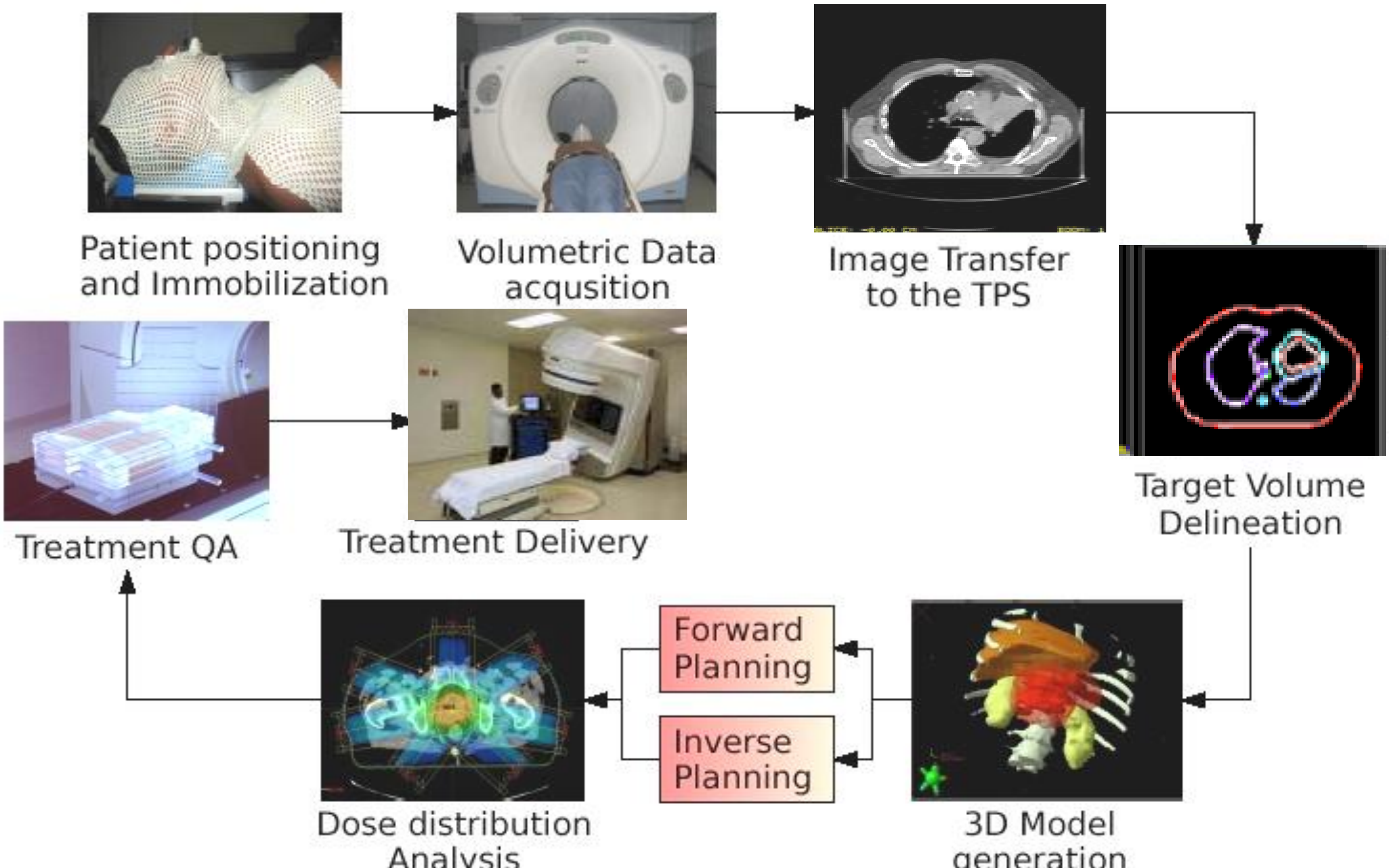


August 2002 Review of the Literature *Arno Mundt MD, University of Chicago*

IMRT – Clinical Process

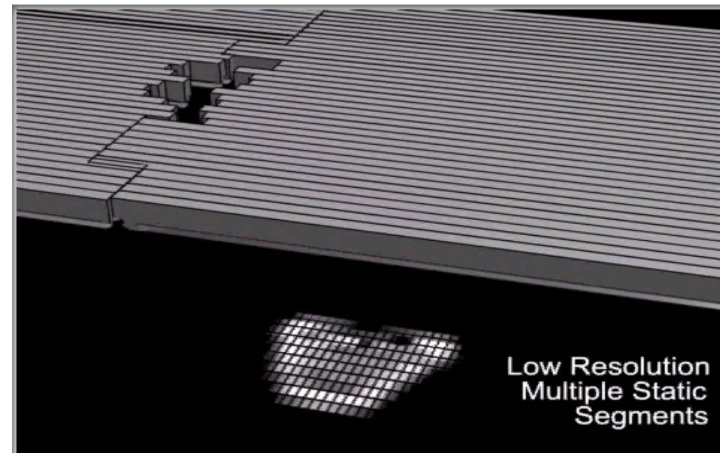
- Imaging for staging
- Immobilization
- Imaging for treatment planning
- Treatment Planning – Forward or Inverse
- Plan verification
- Treatment verification
- Treatment delivery

WORKFLOW OF CONFORMAL RT

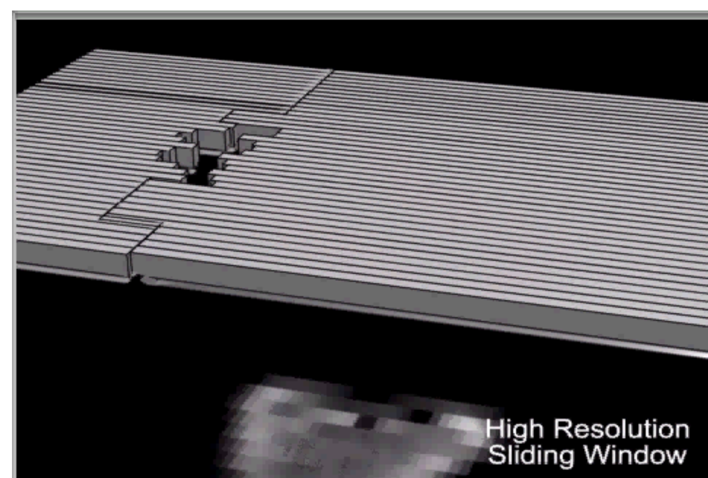


Step and Shoot vs. Dynamic

- Multiple Static Segments, aka:
  - Step and Shoot
  - Move and Shoot
  - Stop and Shoot
  - SMLC

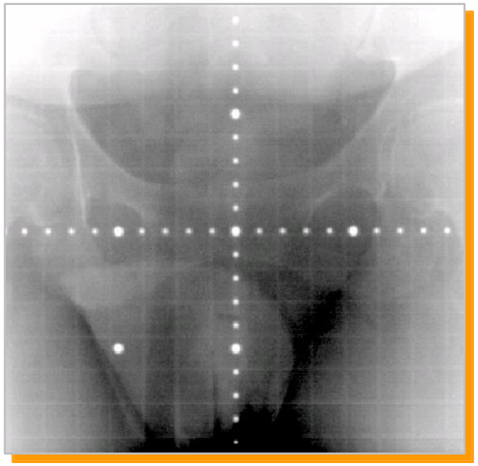


- Fully Dynamic, aka:
  - Sliding Window
  - DMLC
  - Moving Gap



Organ Motion is the CONCERN

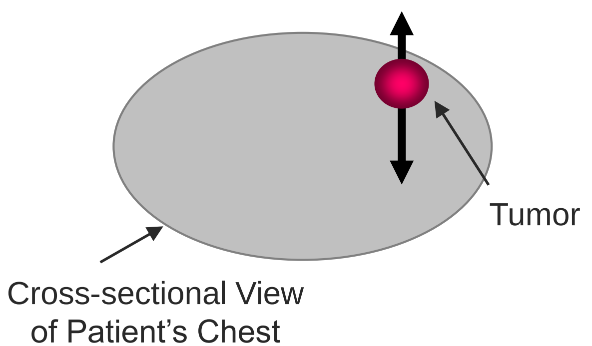
- **"Interfraction"** motion occurs between fractions and primarily is related to changes in patient localization



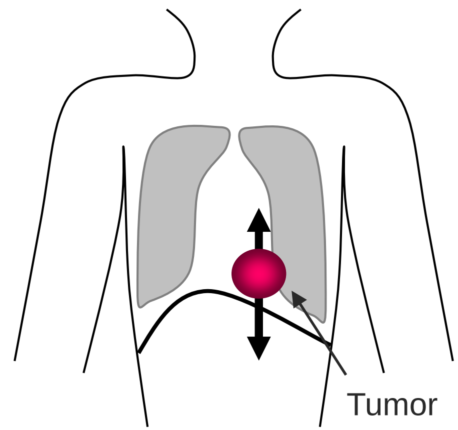
- **"Intrafraction"** motion occurs during fractions and primarily is related to respiration

Tumor Motion During Respiration

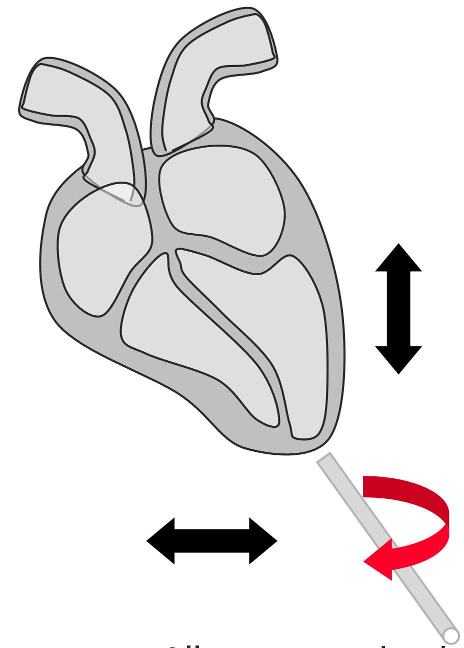
- All tumor motion is complex



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

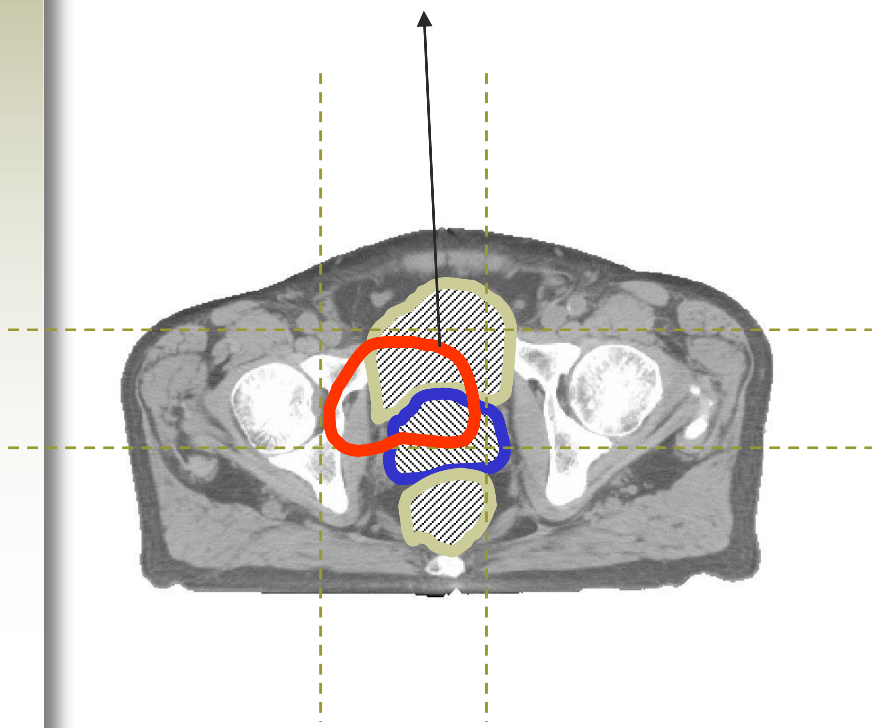
G. Transfer errors

H. Transpositional errors

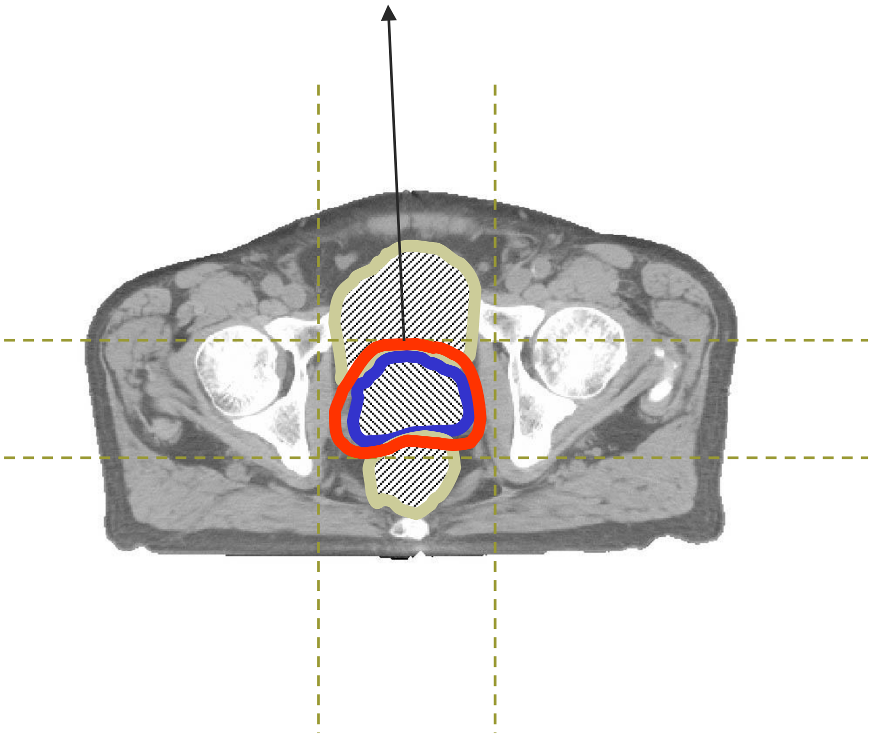
I. Setup errors (either initial or repeat)

Efficient Treatment Also Requires Accuracy !!!

Radiation shaped to target but missing target



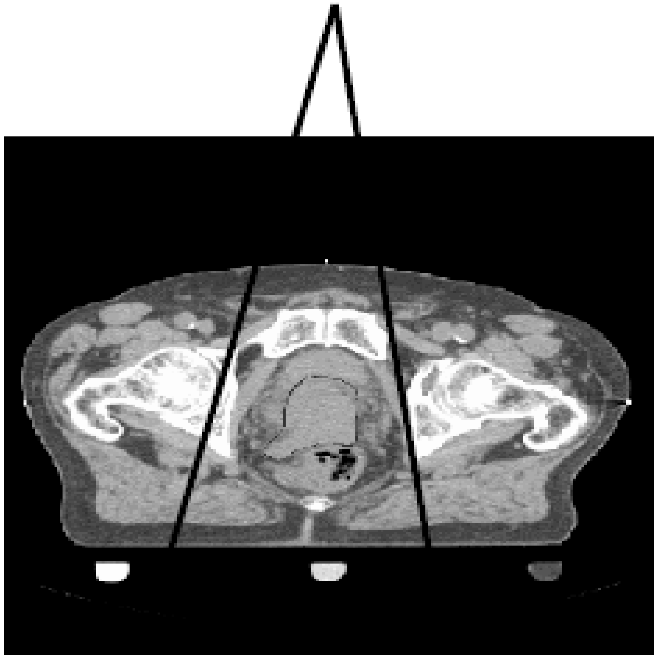
The right target



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



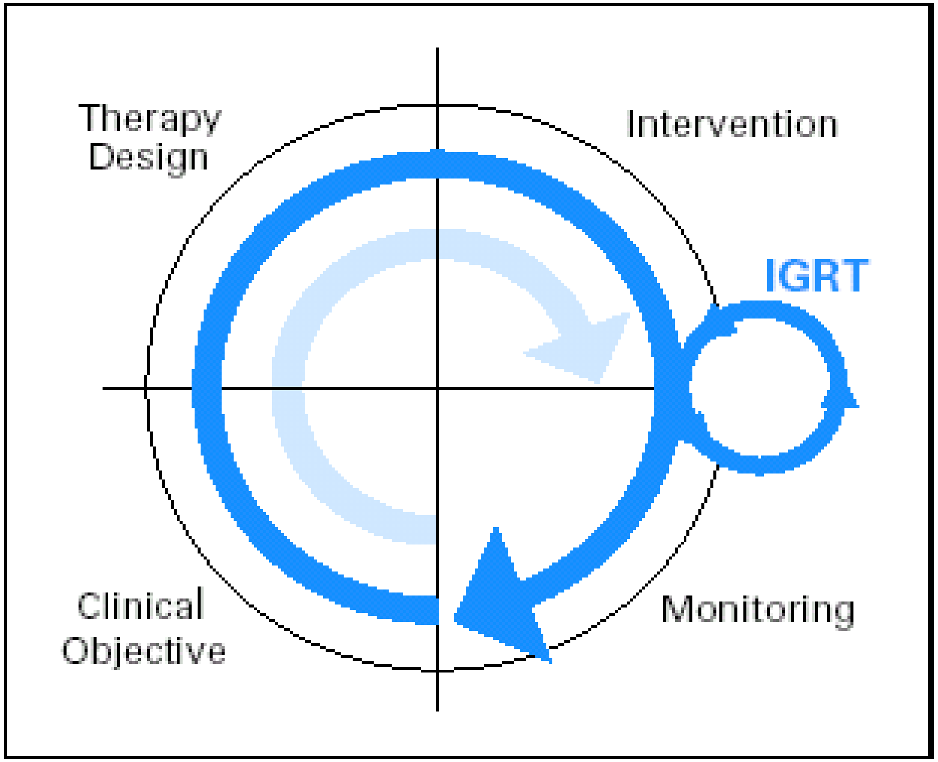
1. Use large margins, irradiating too much healthy tissues

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.

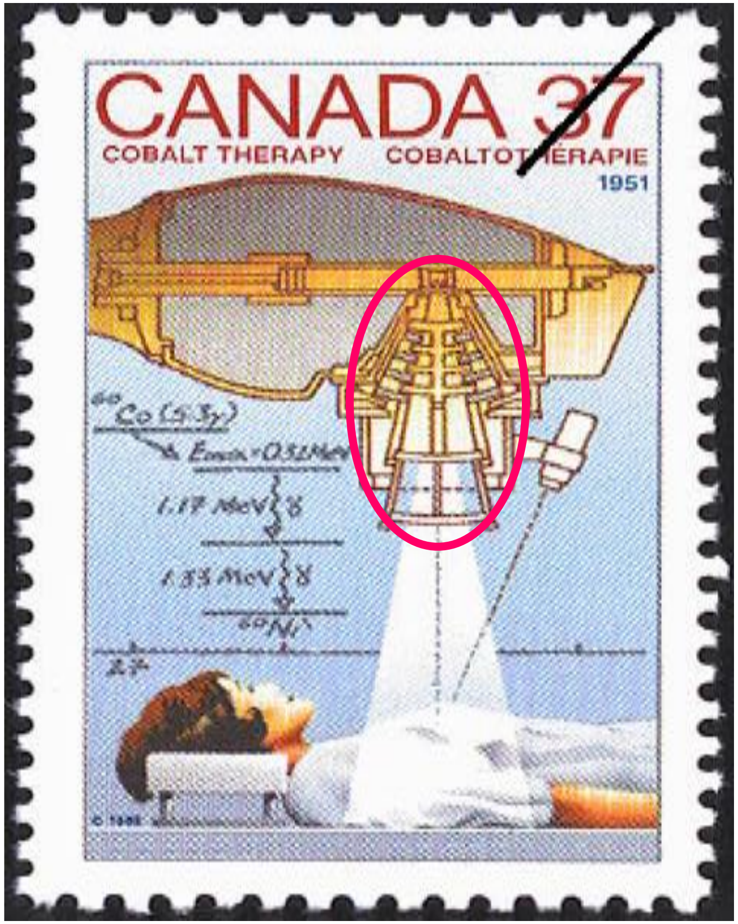
Four- Dimensional Radiotherapy (4DRT)

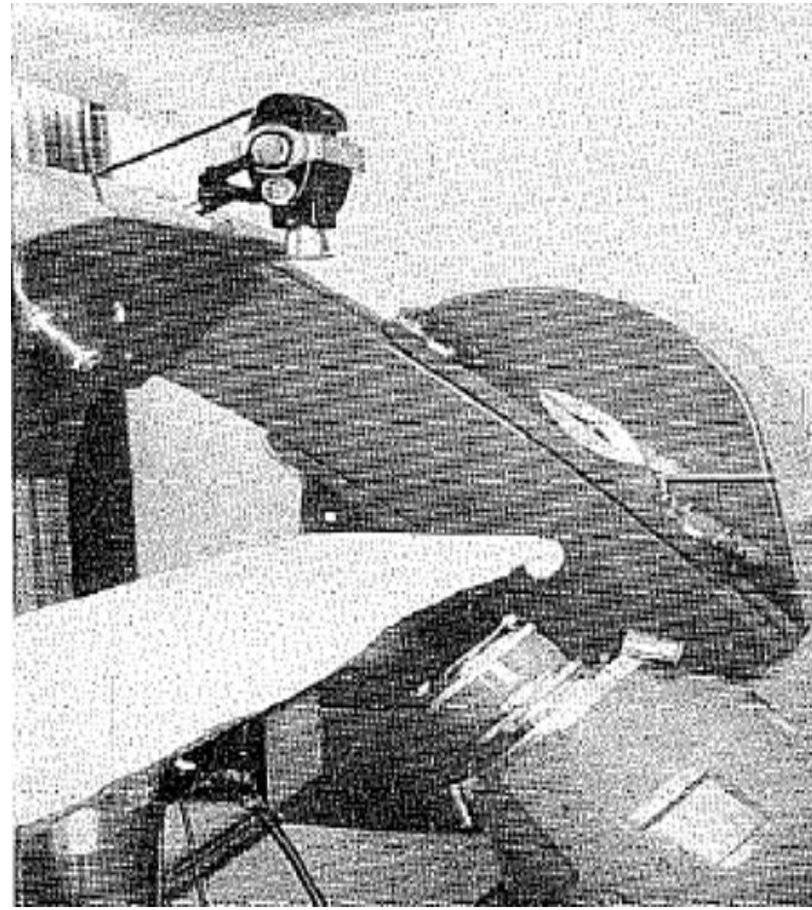
- IGRT in which the localization accuracy– not only in space but also in time – is improved

- 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 SonArray I-Beam Restitu	Video Subtraction Photogrammetry AlignRT Real-Time Video	EPID CyberKnife Novalis RTRT Gantry-Mounted Prototype Tohoku IRIS Commercial Varian OBI Elekta Synergy	In-Room CT FOCAL, MSKCC CT-on-Rails Primation Varian ExaCT Tomotherapy MV Cone Beam CT Siemens 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

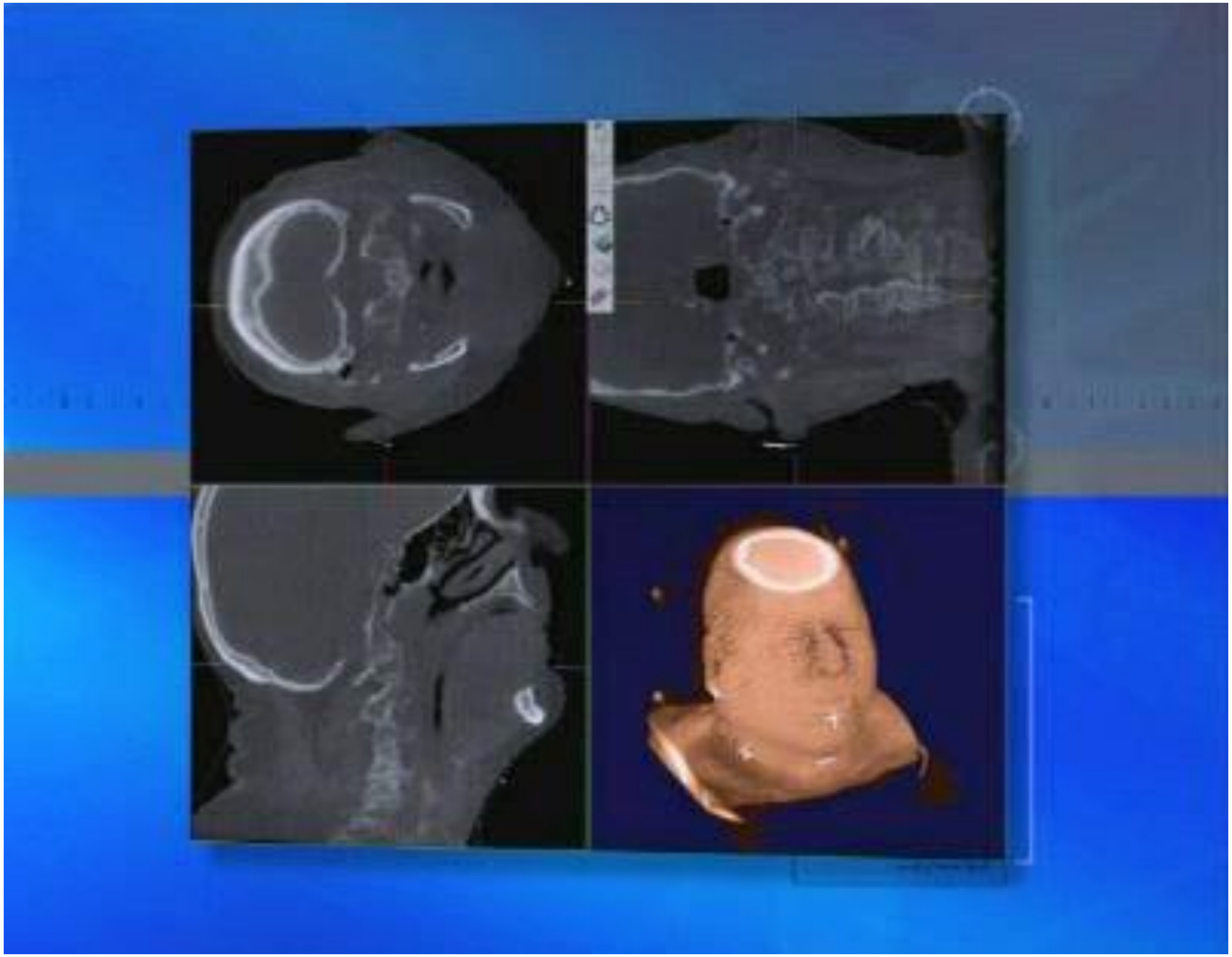
  C. Implanted fiducials
  (Deformation is a problem, Less inter user variation, Good stability)

  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

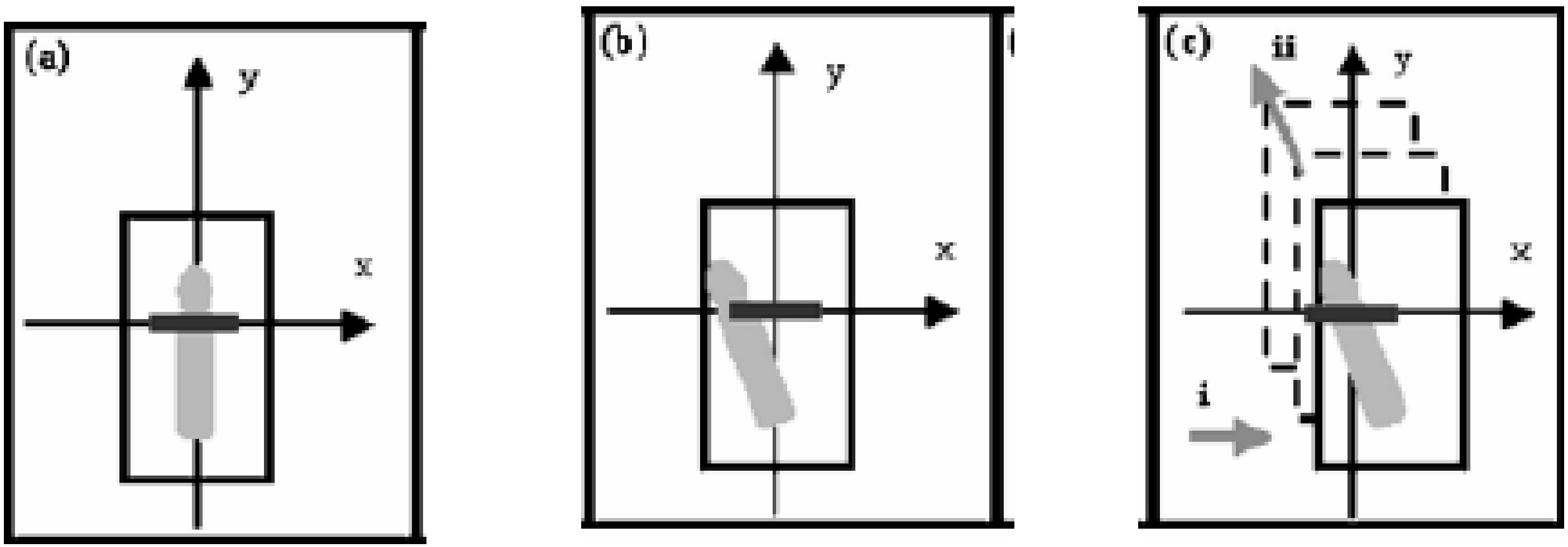


How to Correct for Displacements

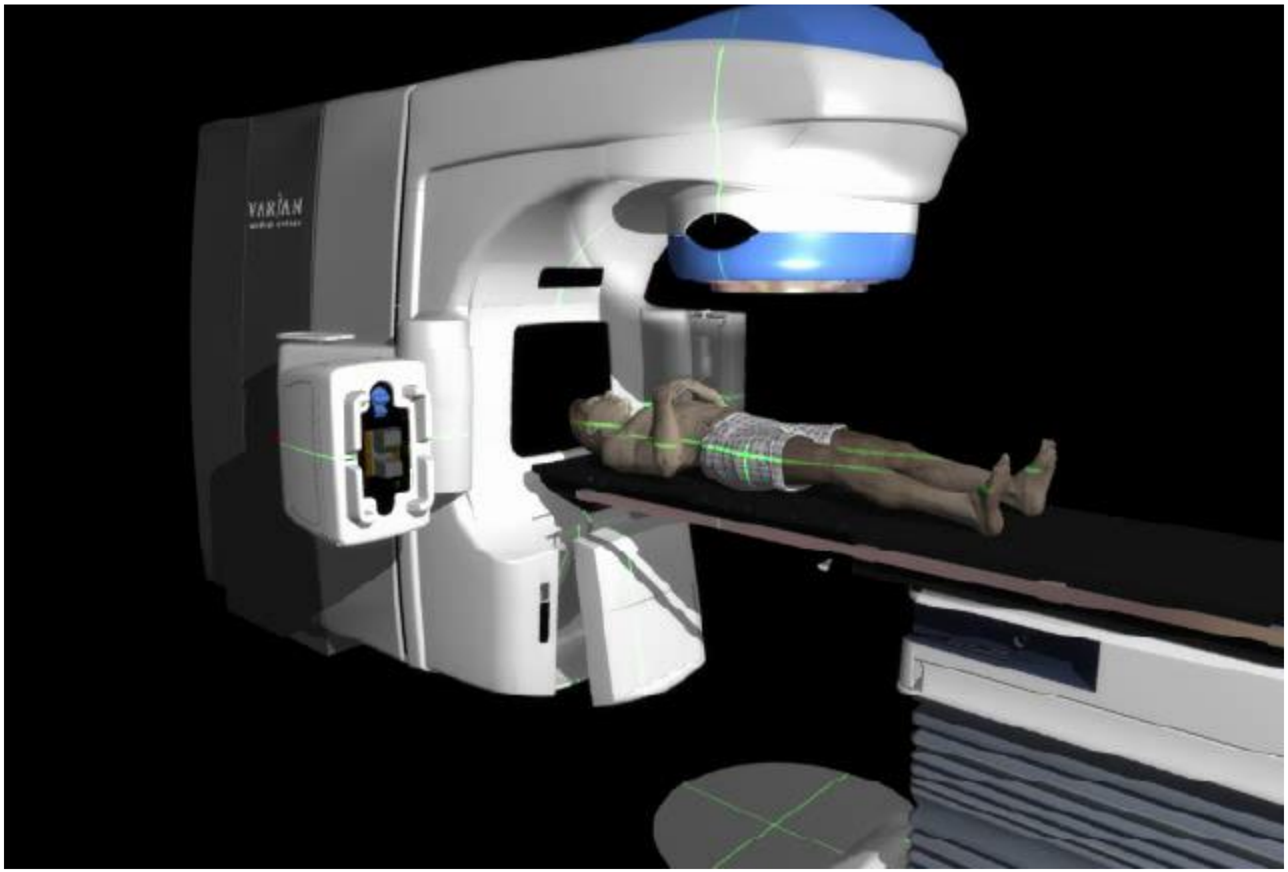
- Couch corrections
- Gantry and collimator angle adjustments
- Modification of multi-leaf collimator leaf positions

Couch Corrections

Correction by lateral couch shift



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


VARIAN

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

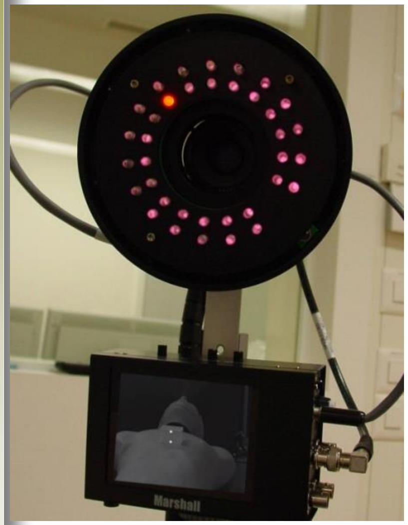
(ii) Gated/breath hold CT

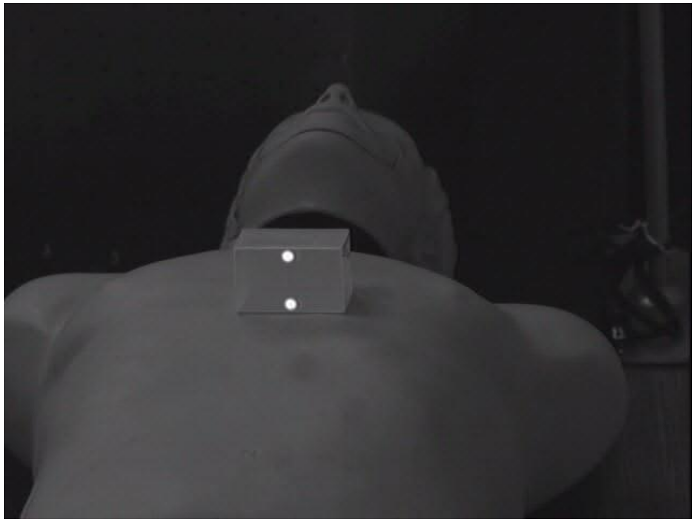
Prospective respiratory correlation

(iii) 4DCT

Retrospective respiratory correlation

RPM Respiratory Gating™ System

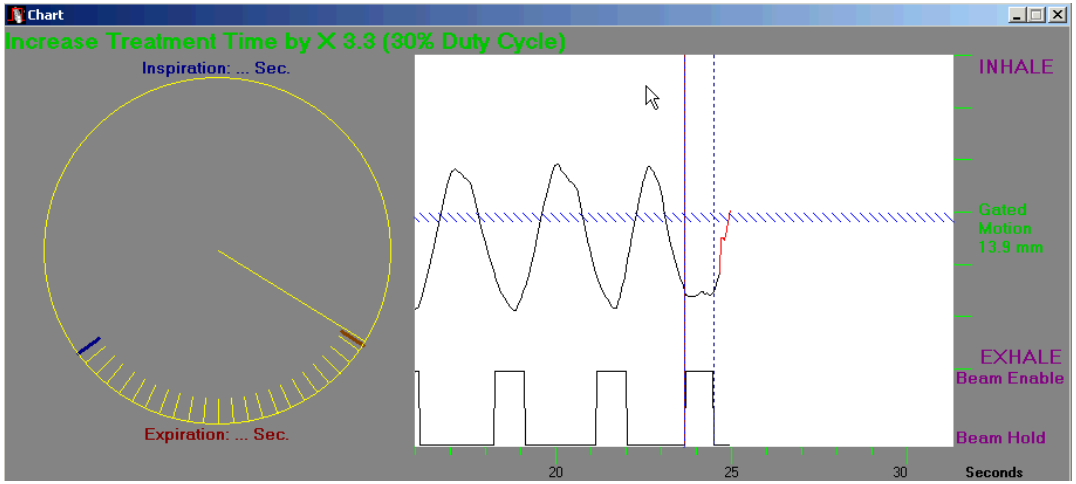


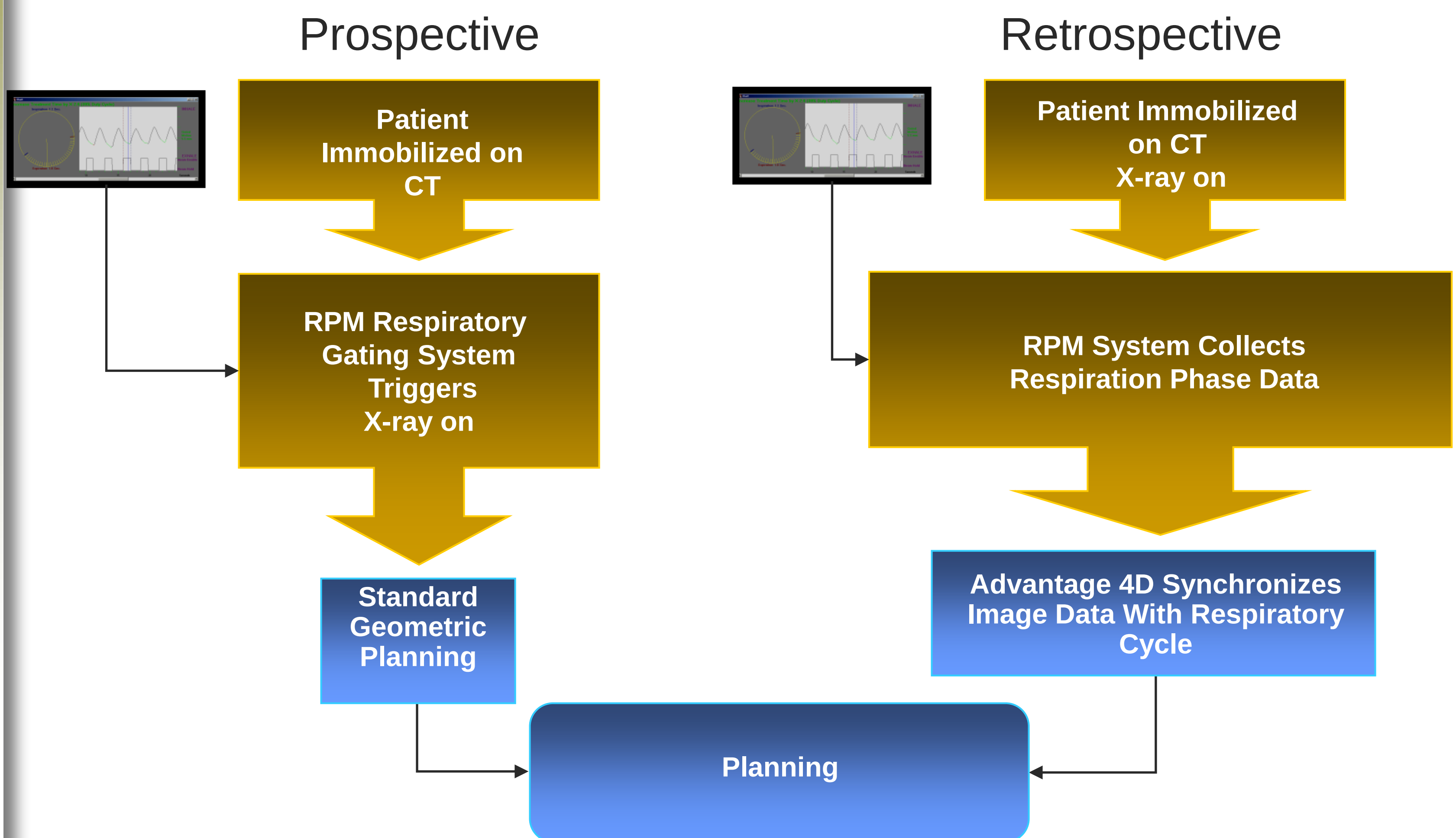
Varian patent 6,279,579

Literature:
- Kubo 1996, 2000a, 2000b
- Ramsey 1999a, 1999b
- Slotman & Lagerwaard 2004
- de Pooter & Alberty 2004
- Pedersen et.al. 2004

Data courtesy AZ Sint Augustinus,
Wilrijk, Belgium

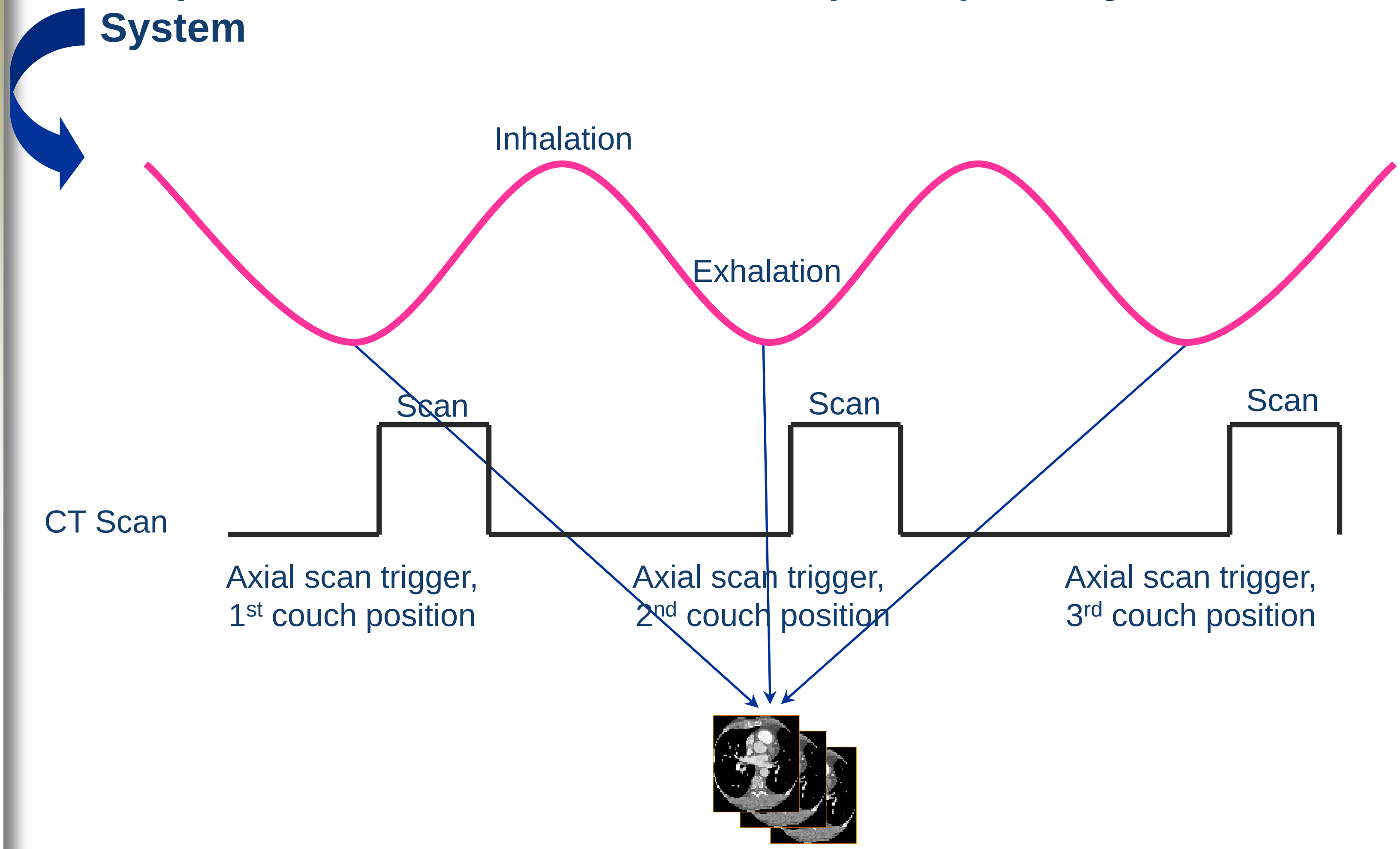


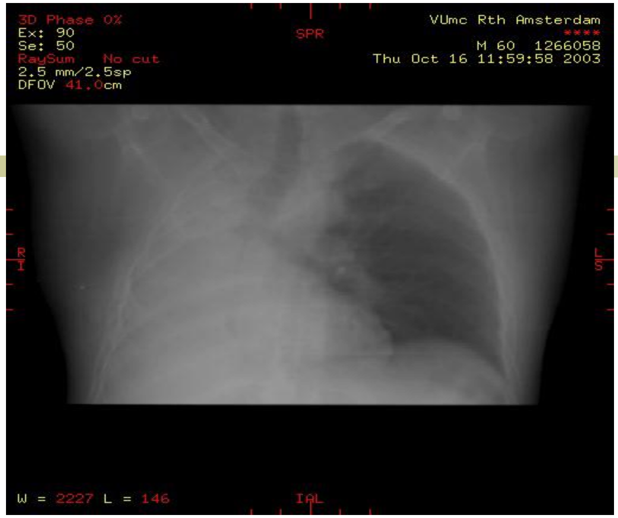
4D CT Image Acquisition

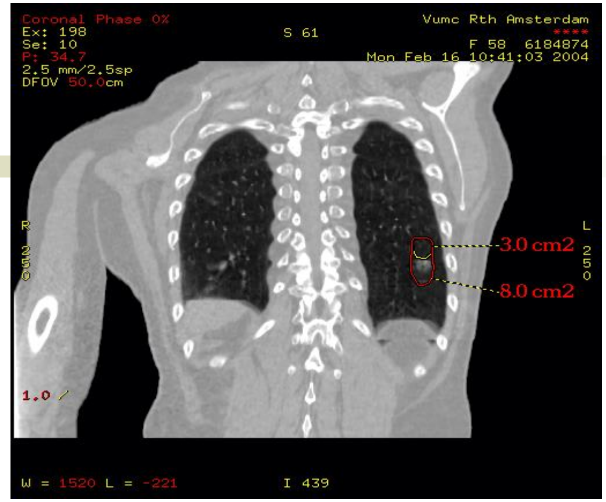


Prospective CT Image Acquisition

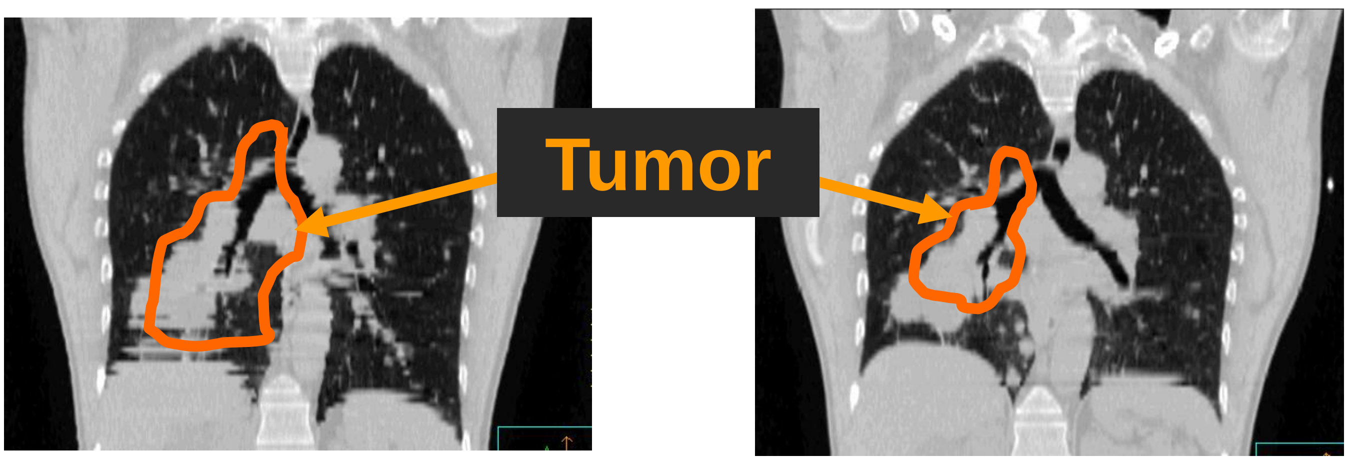
Respiration Waveform from RPM Respiratory Gating System







Prospective Gating

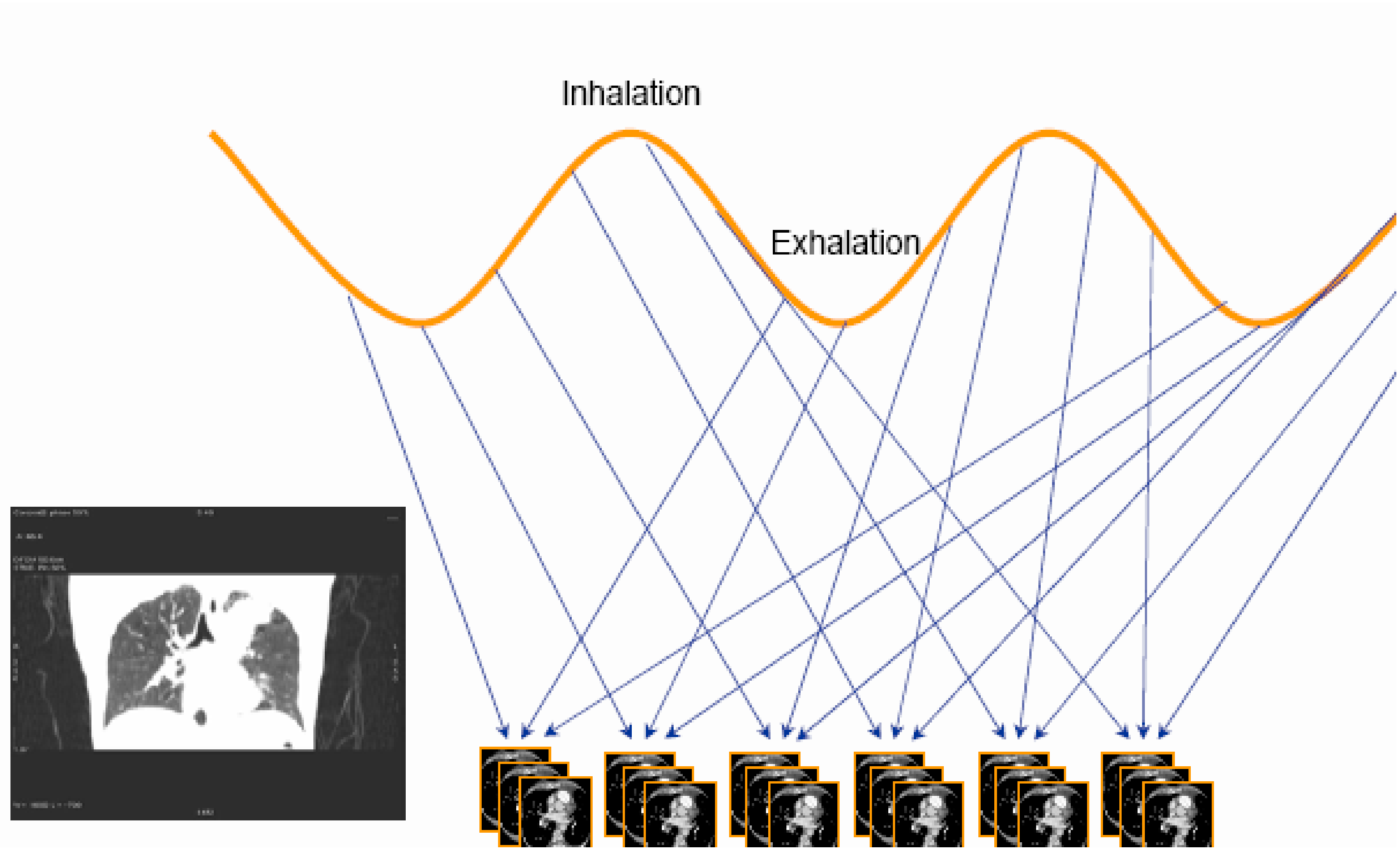


Conventional CT Image

Gated CT Image

Images Courtesy Medical College of Virginia, Richmond VA

Principle of 4D scanning



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

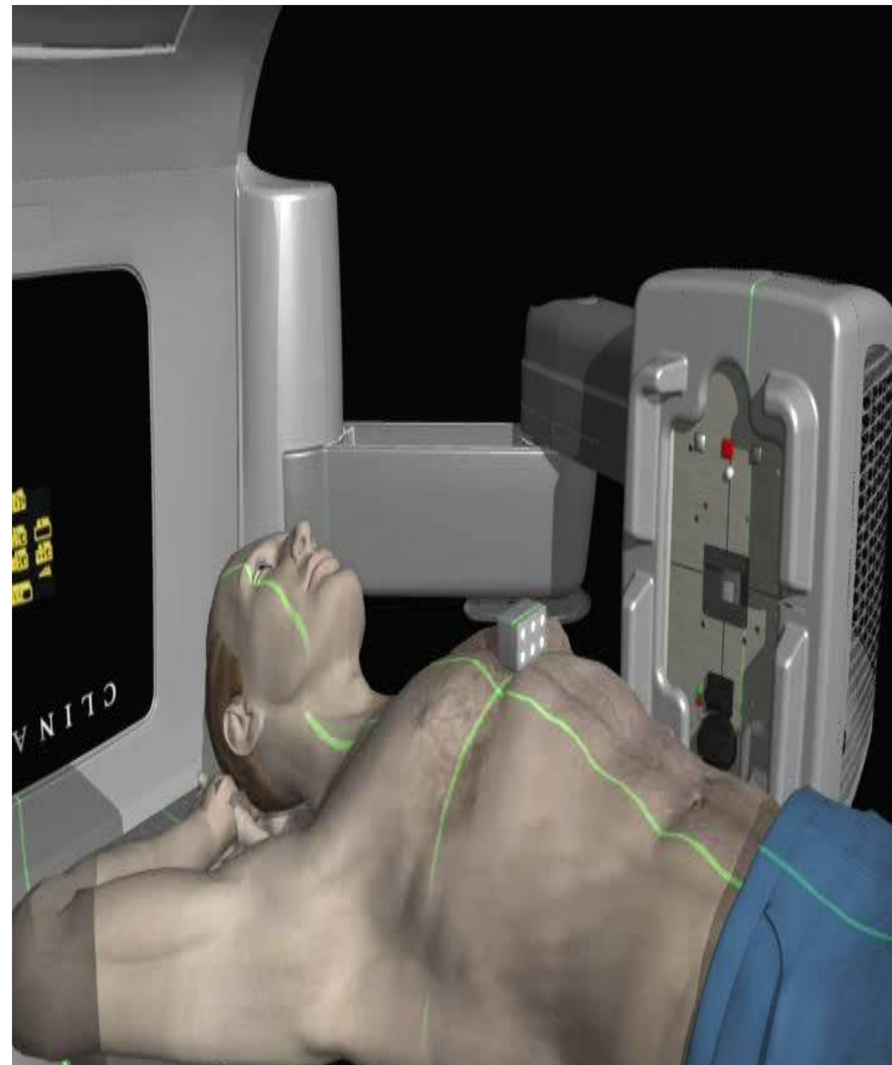
- System consists of an infra-red camera that is mounted to the foot of the CT

- Markers block containing 2 reflectors.

- The marker block was placed on the patient's skin in the abdominal region

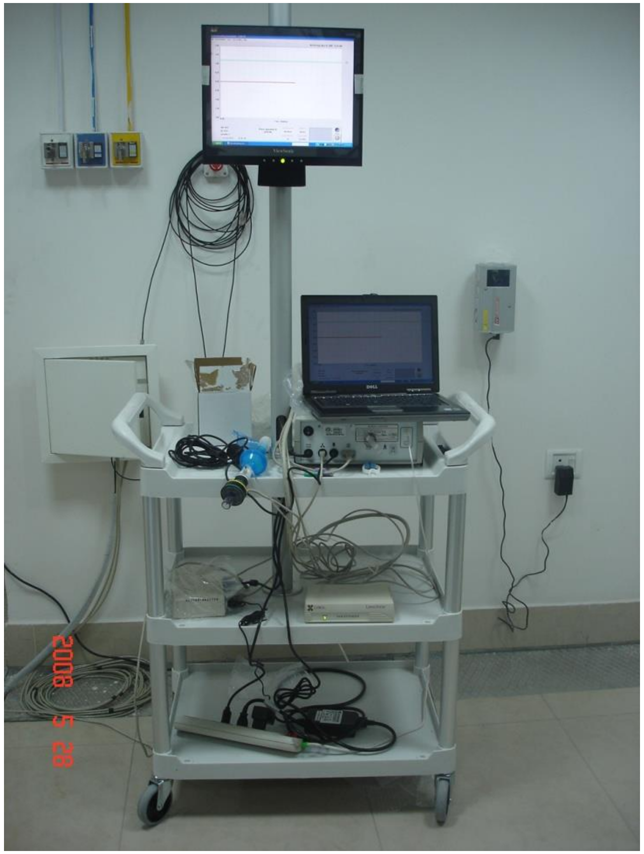
- Surrogate signal = abdominal surface motion correlation to tumor motion

- The x-ray on signal from the CT scanner was recorded synchronously with the respiration signal

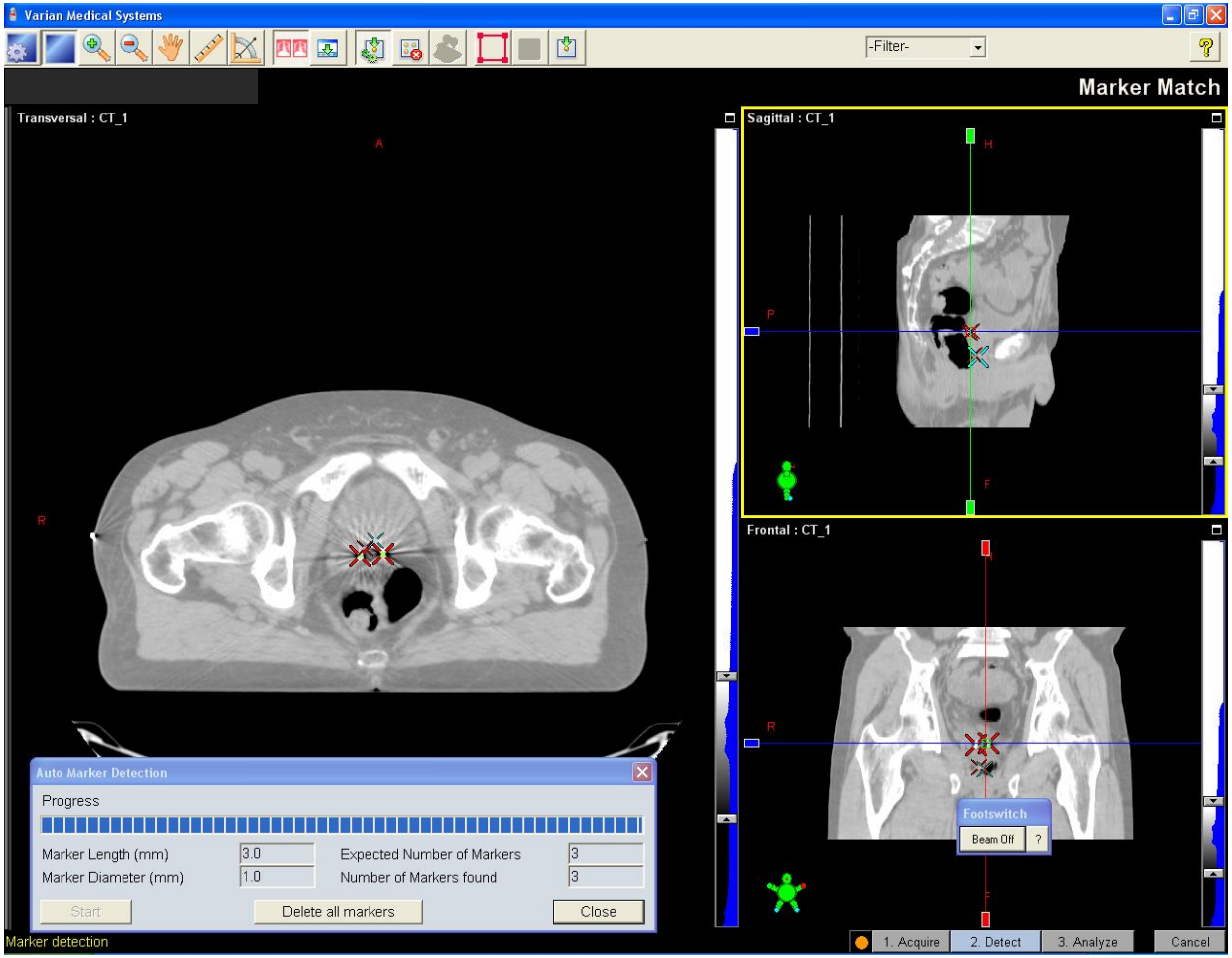


Active Breathing Control (ABC)

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

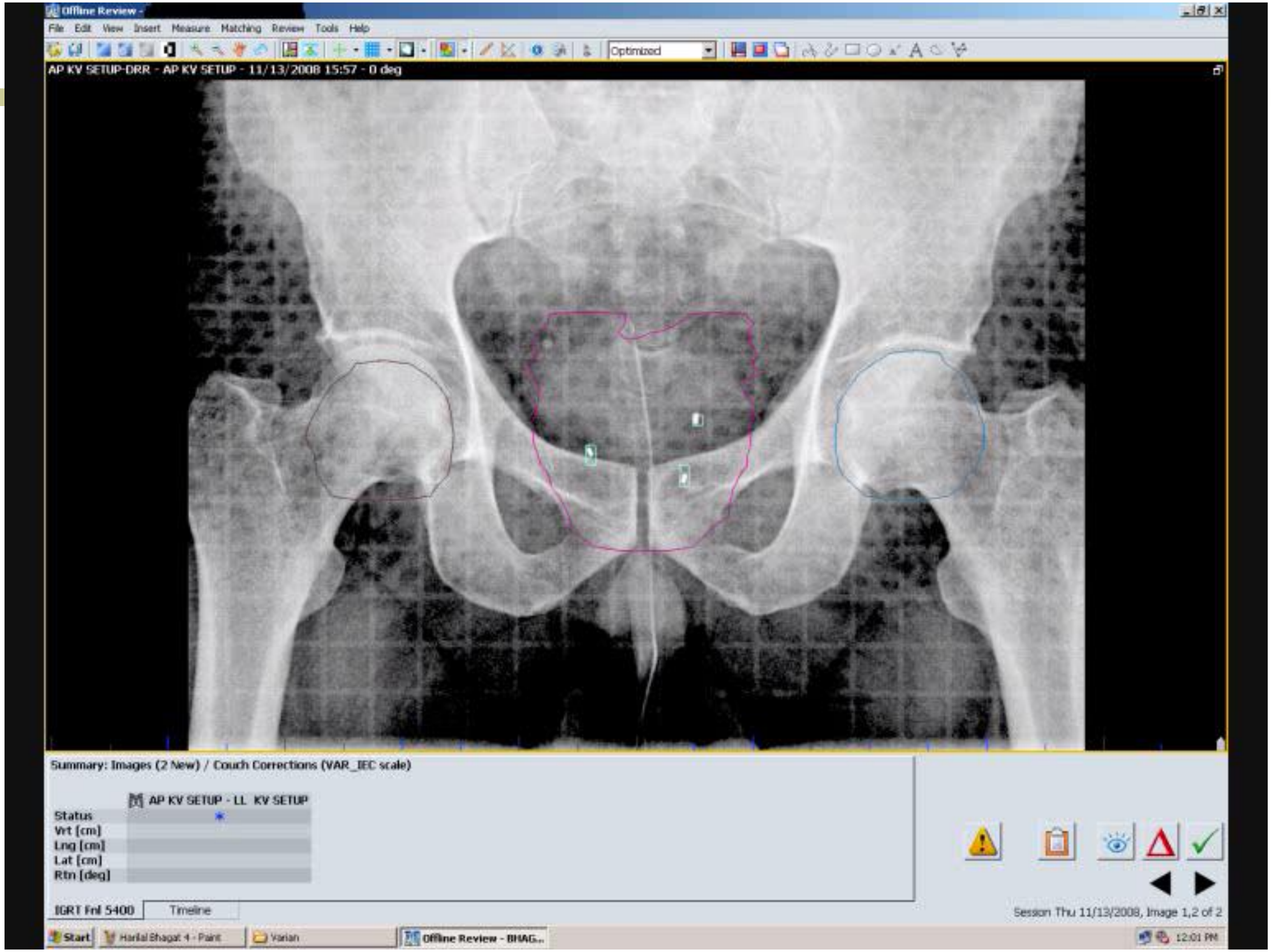


On-Board Imager – Marker Match™



Find Markers in Planning CT

FDA 510(k)


Offline Review -
File Edit View Insert Measure Matching Review Tools Help
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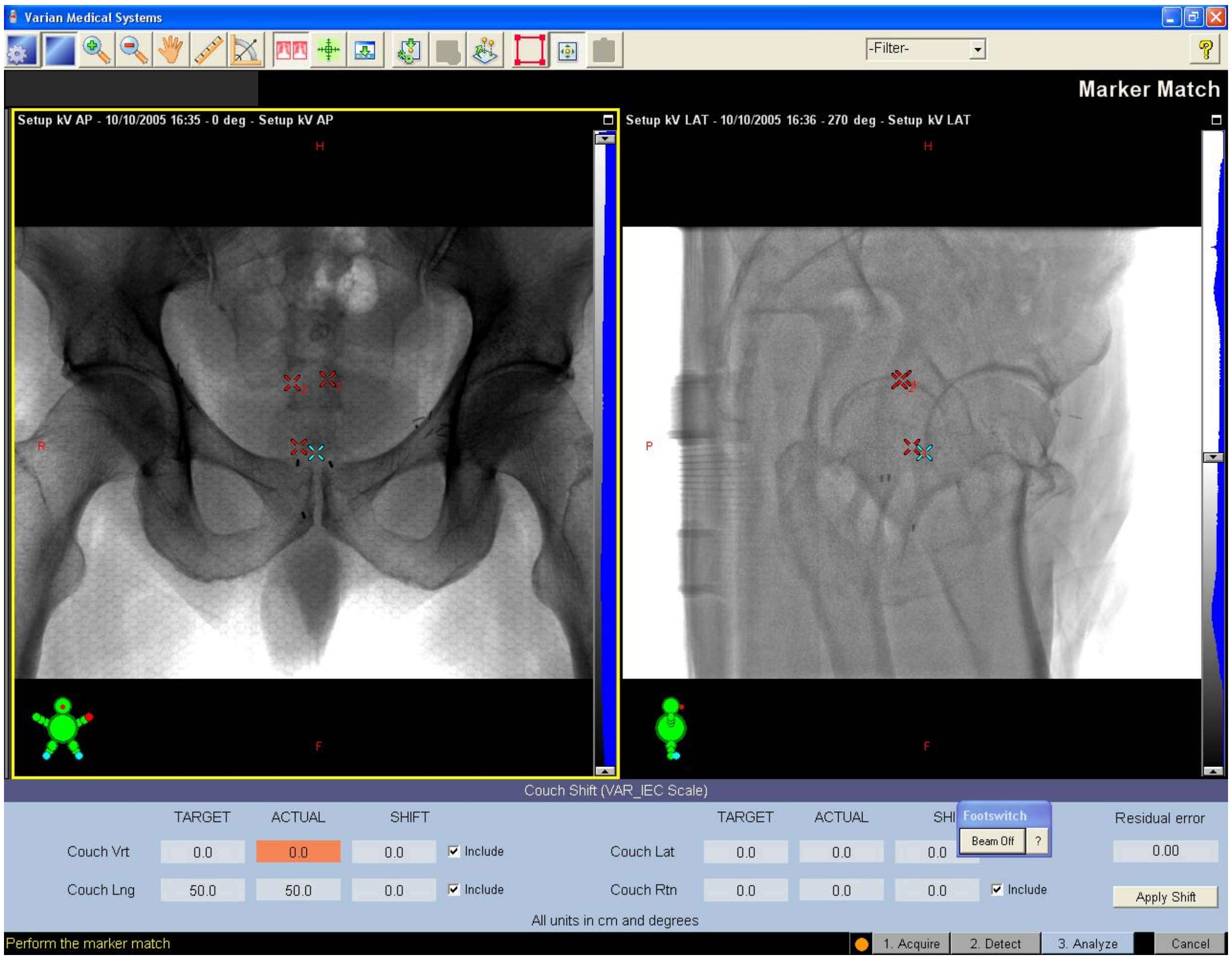
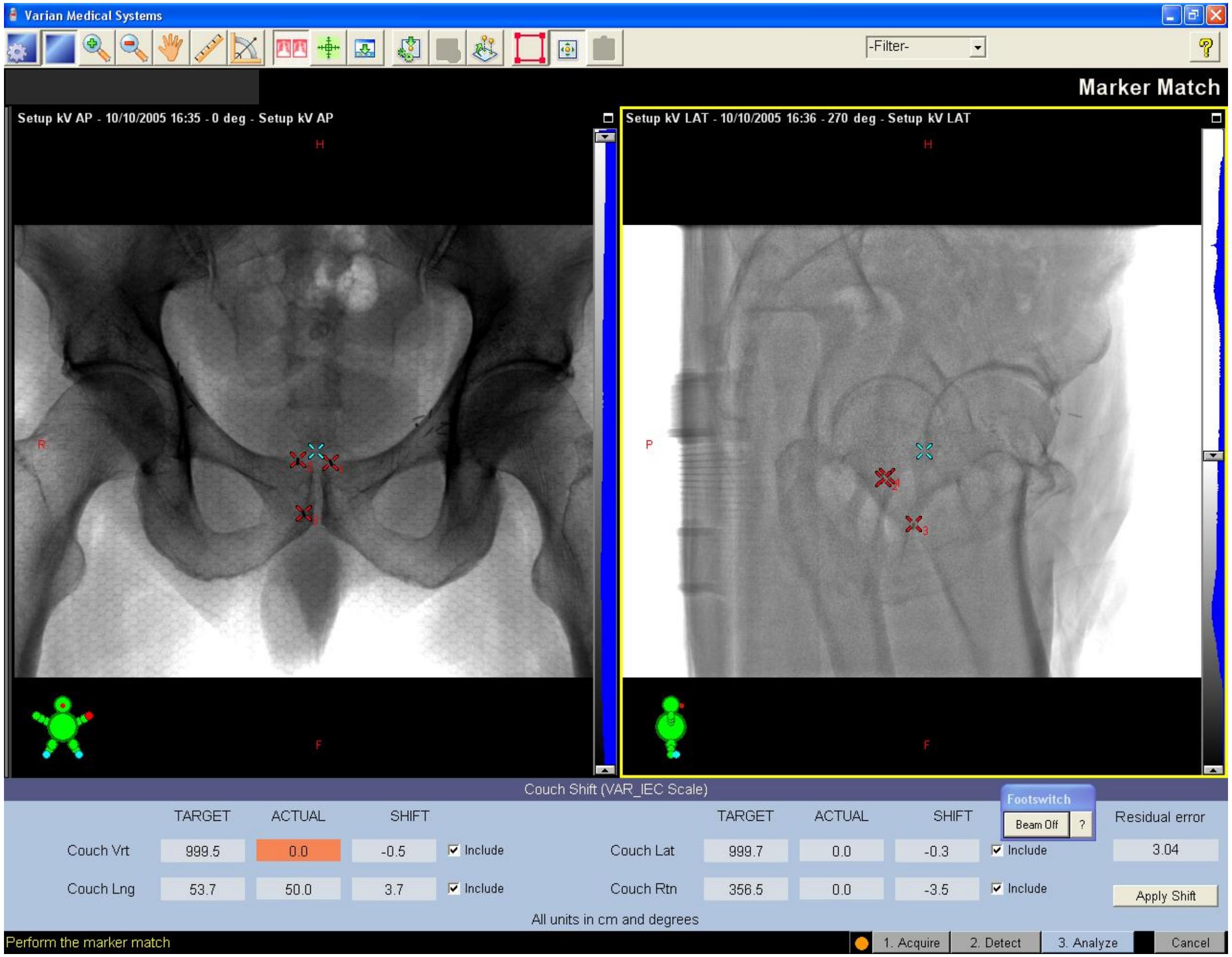
On-Board Imager – Marker Match™



Acquire Radiographic Images

FDA 510(k)

On-Board Imager – Marker Match™

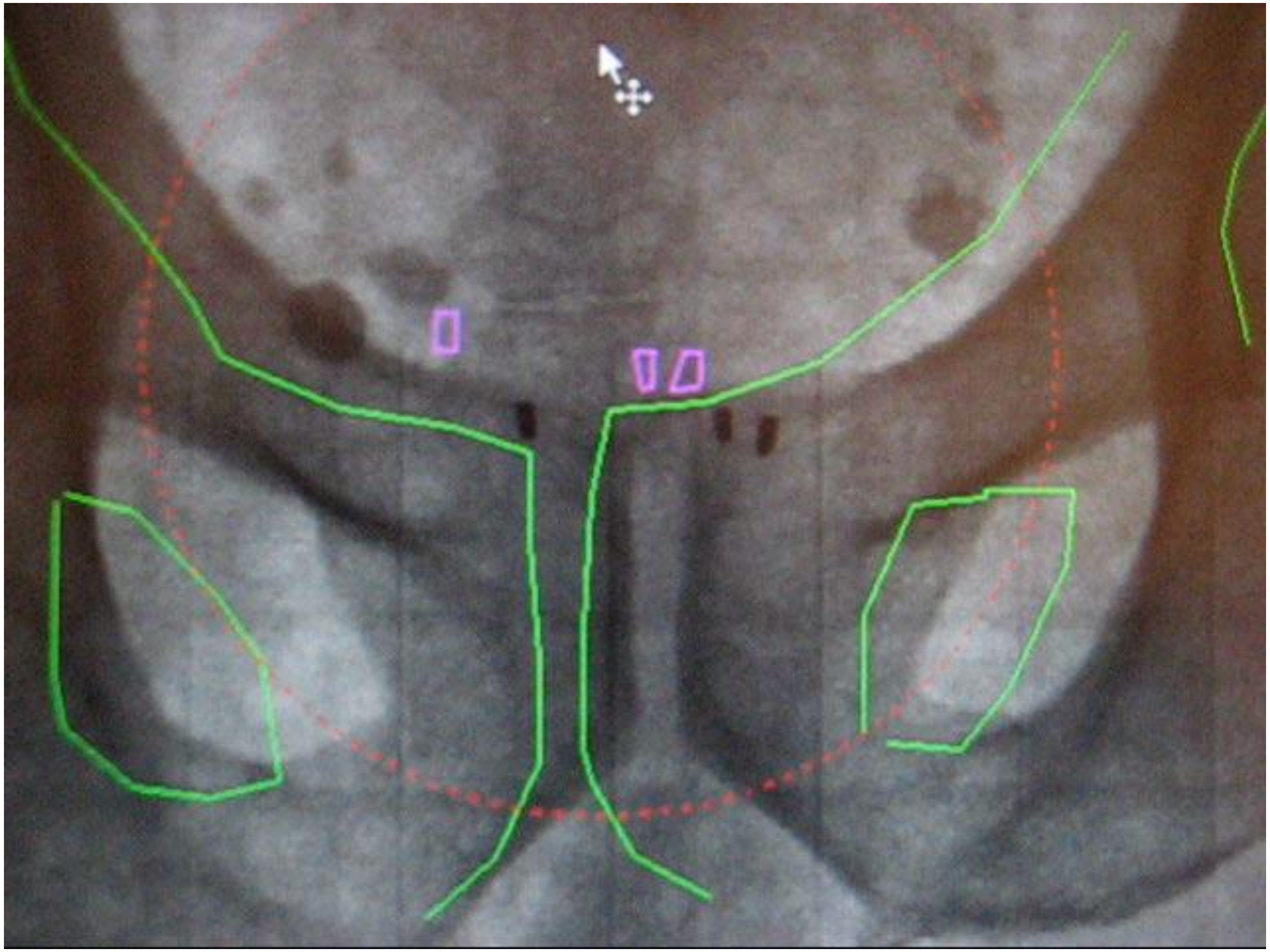


Match/align Marker Template with actual setup images

➔ Calculate couch motion required to correct setup

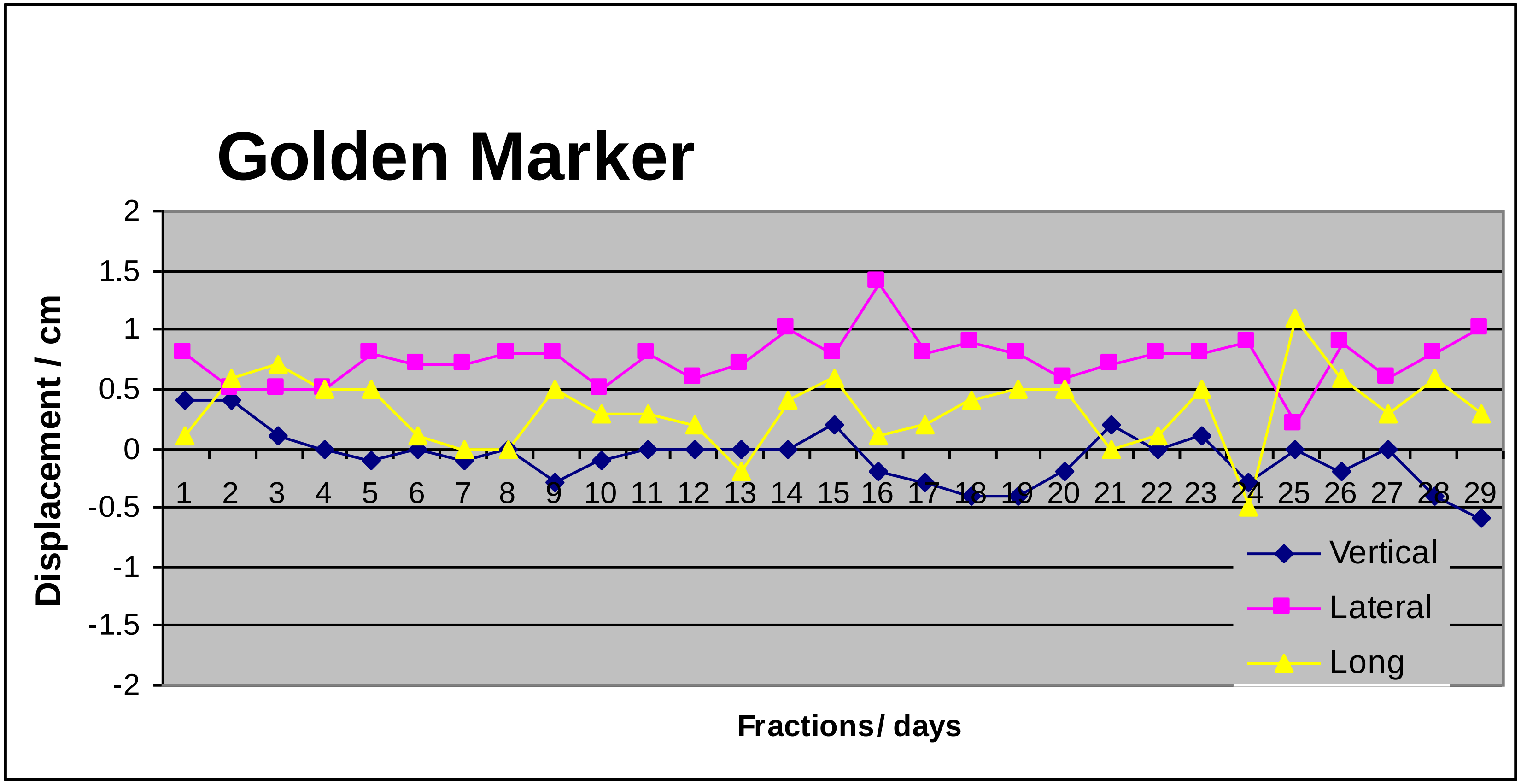
FDA 510(k)

Marker Match – Clinical Results



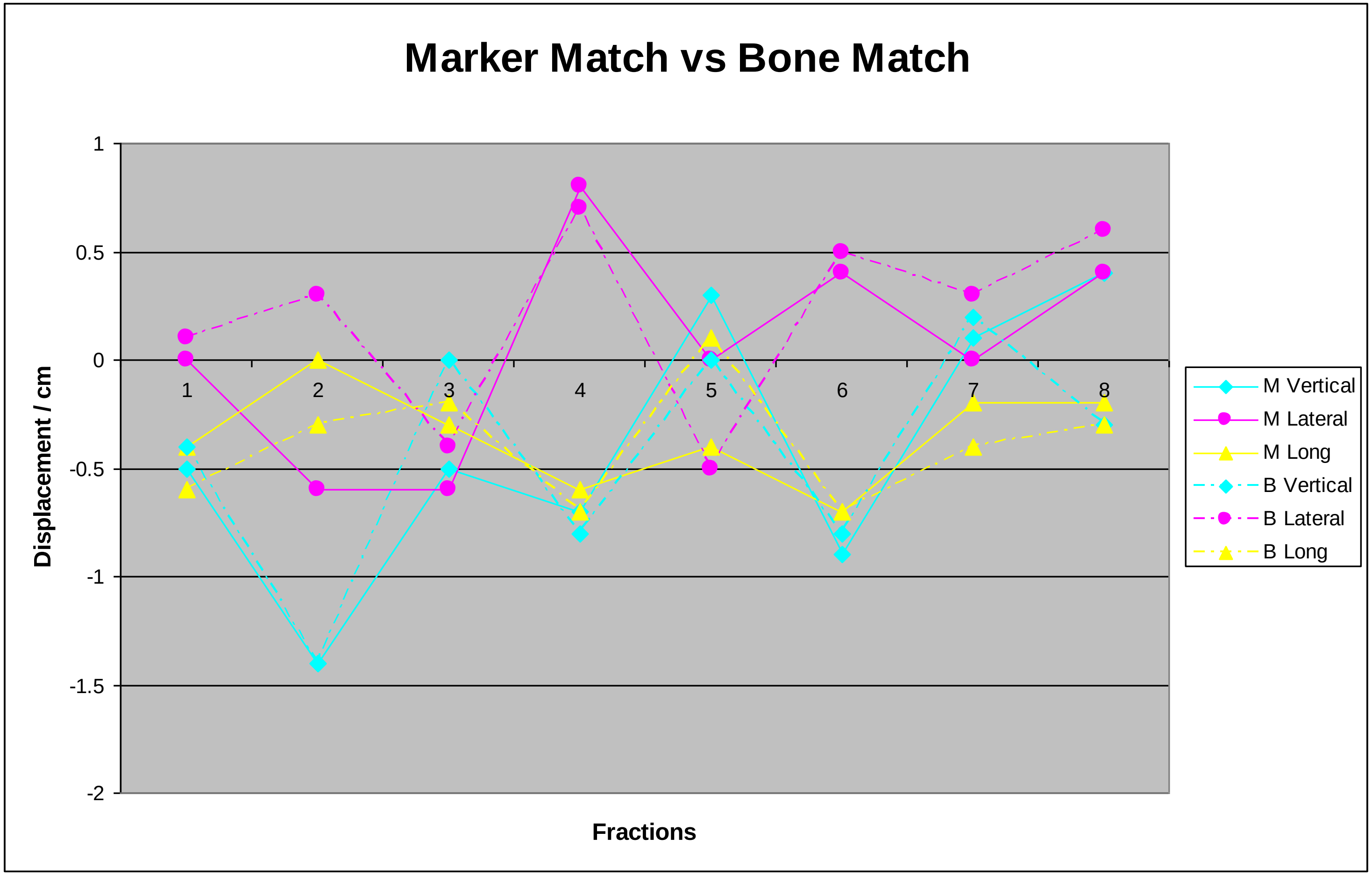
FDA 510(k) - Images courtesy Karolinska University Hospital, Stockholm, Sweden

Marker Match - Shifts for one patient



Data courtesy Karolinska University Hospital, Stockholm, Sweden

Marker Match - Markers vs. Anatomy



Data courtesy Karolinska University Hospital, Stockholm, Sweden

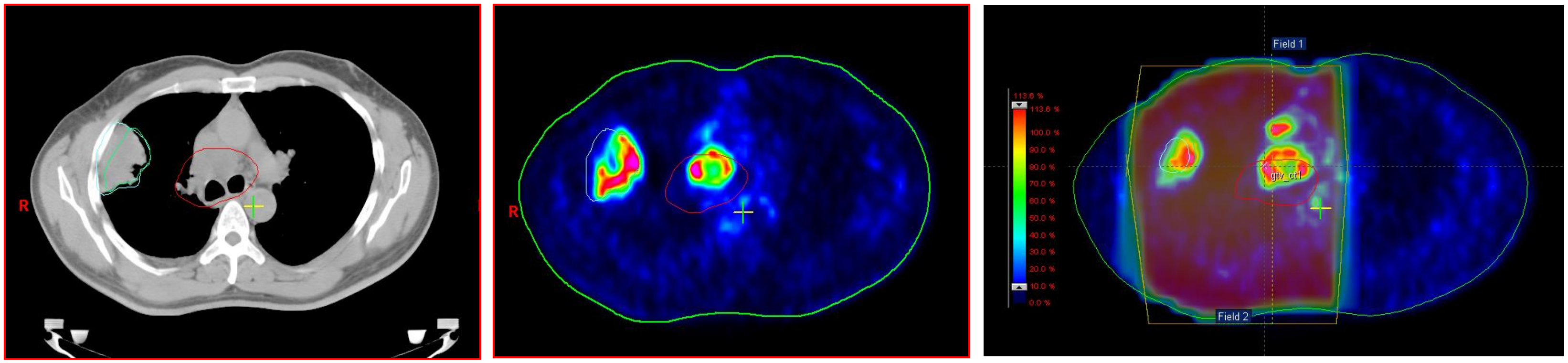
METABOLLICALLY AIMED RADIOTHERAPY MART

PET GUIDED
IMRT

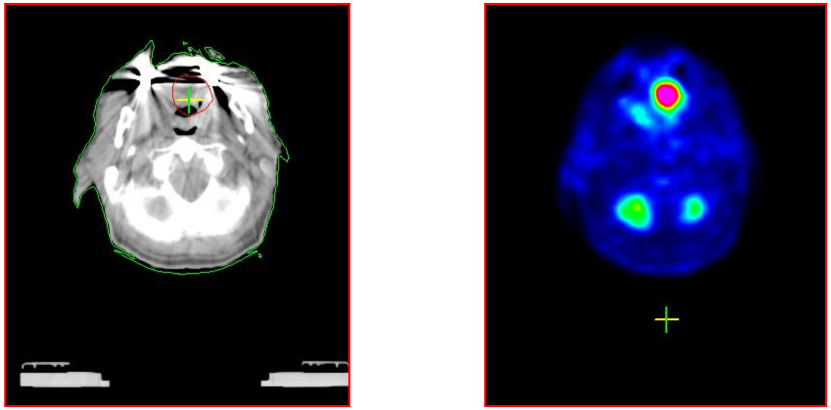
IMPROVED TUMOR/NON TUMOR
RADIATION DOSE

HYPO-FRACTIONATION
30-40 → 5-10 fractions

PET – CT fusion for Planning

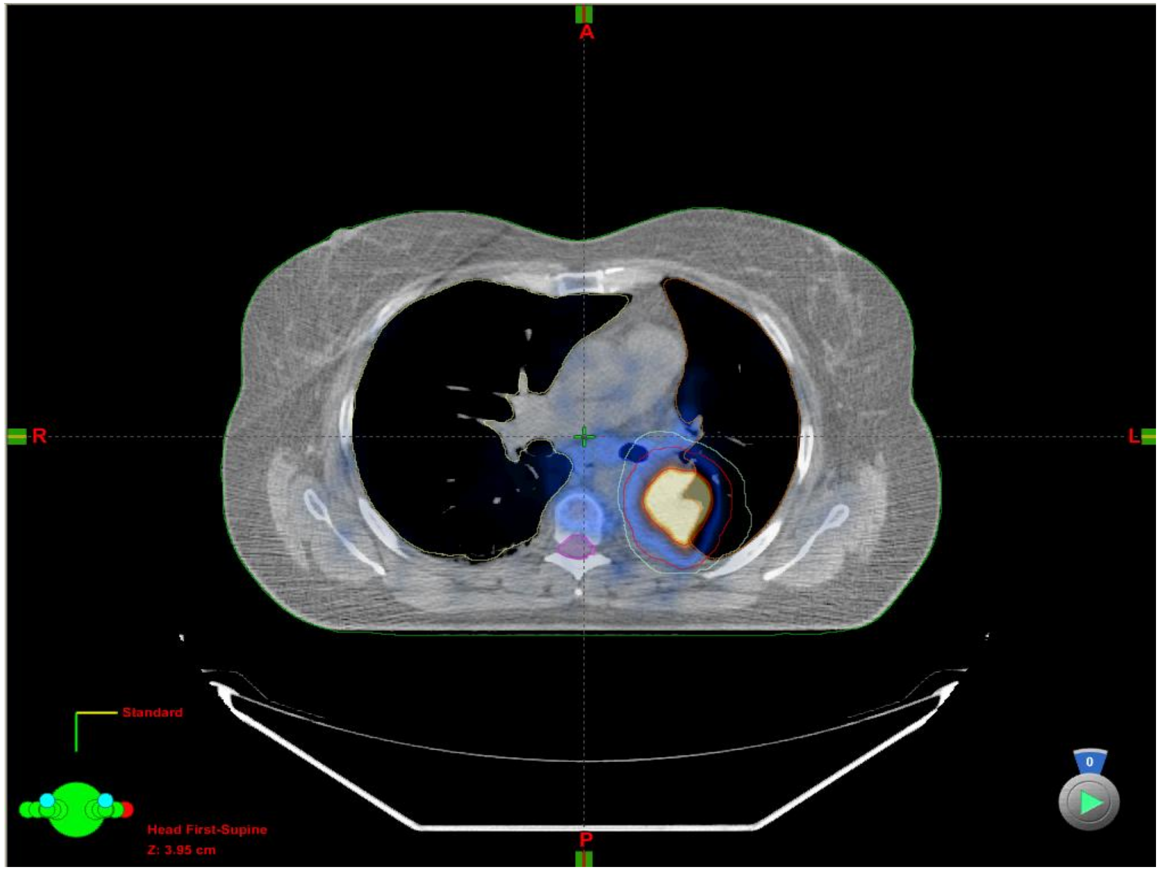


PET/CT Lung Primary



PET/CT Head and Neck Primary

Eclipse 4D – PET CT



TOMO is the Buzzword in Imaging Technology

Computed TOMOgraphy

SPECT TOMOgraphy

Helical TOMOtherapy

MR TOMOgraphy

Positron TOMOgraphy

All these revolutionary technologies are based on ring gantry design

What is Helical TomoTherapy ?

- TomoTherapy literally means “Slice Therapy”
- It is derived from the word ‘Tomography’
- Helical Tomotherapy is the delivery of IMRT using helical rotational delivery in the manner of a CT scanner
- A modified Linac fitted into CT ring gantry configuration for therapeutic radiation using rotating fan beam modulated by multileaf collimators
- System uses tomographic imaging for treatment verification and tomographic reconstruction for optimal treatment

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

Advantage

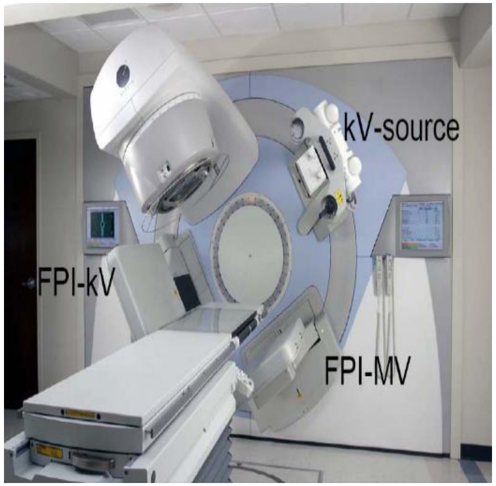
- it does not require the extensive modification of a Linac
- CBCT imaging system uses a large detector and a single rotation

Disadvantage

- 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

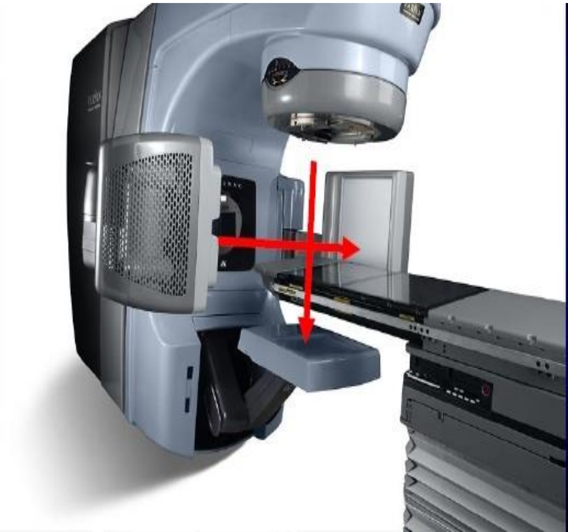


<u>Advantages</u>

- real-time information is available
- No surrogates required

<u>Disadvantages</u>

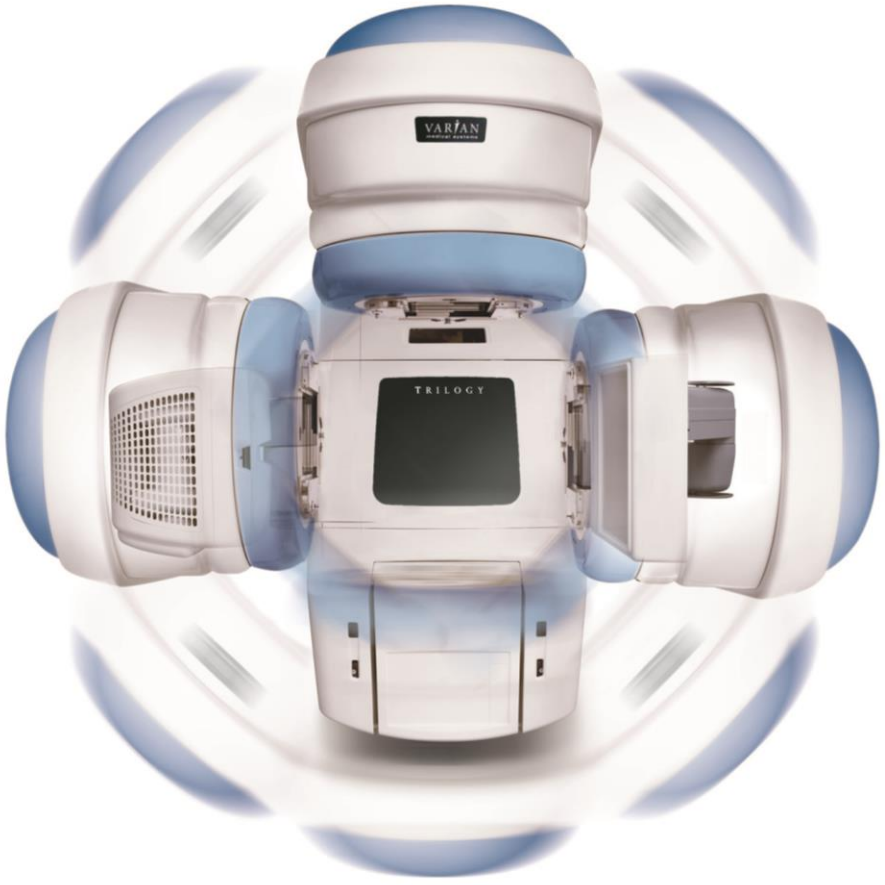
- Mechanically less stable
- Requires careful calibration



IMRT in a Single Arc

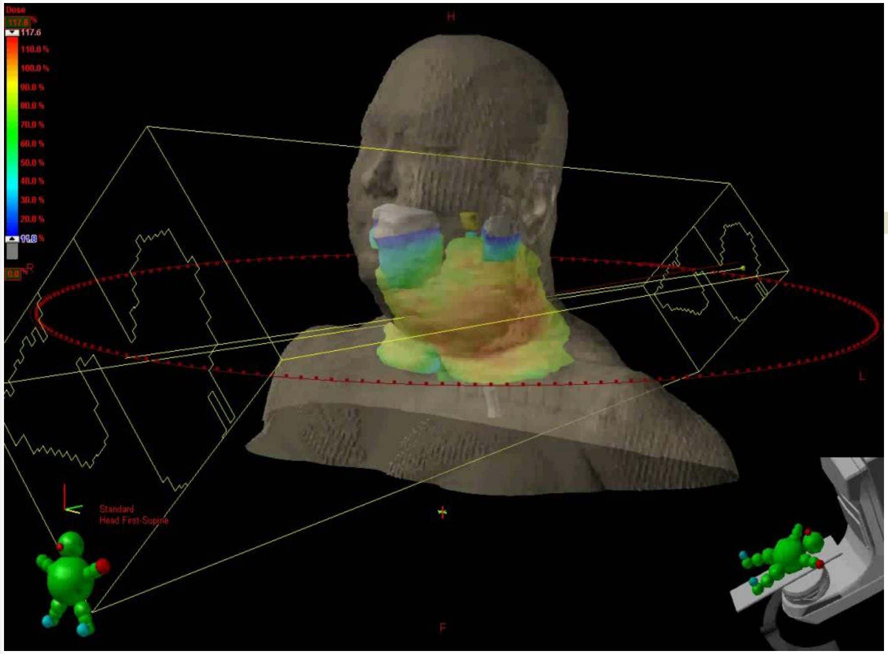
Dynamic Radiotherapy Objectives

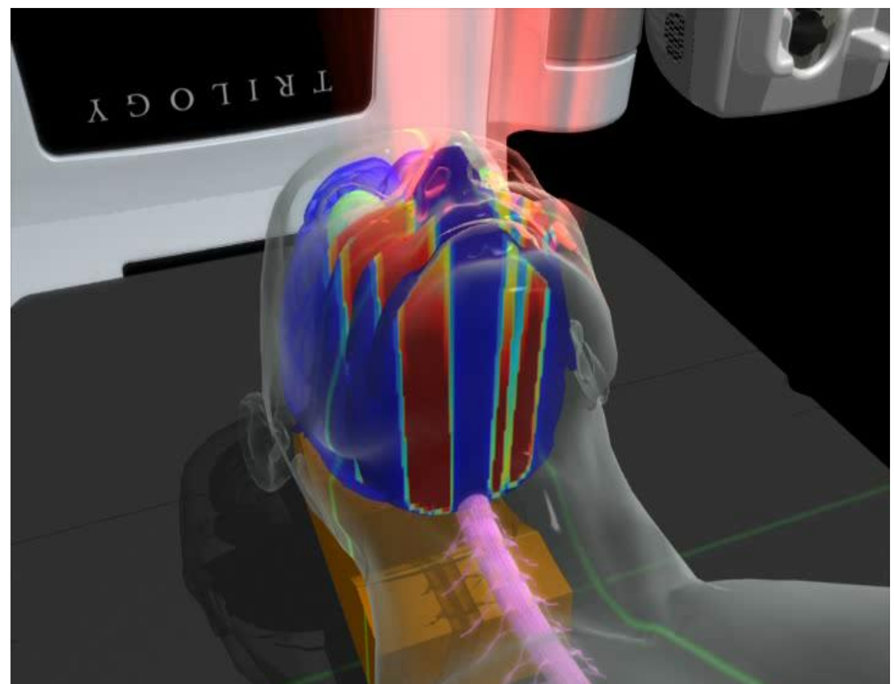
- Single arc IMRT
- IMRT quality
  - Uniform target coverage
  - Improved normal tissue sparing
- Treat in 2 minutes or less
  - Highly efficient
  - Low peripheral dose
- Simple planning and delivery



- **2 min Imaging & Repositioning**

- **2 min Treatment**
  - Less than 600 MU/ 2Gy
  - Variable gantry speed
  - Variable dose rate
  - Inter-digitating MLC
  - Dynamic MLC

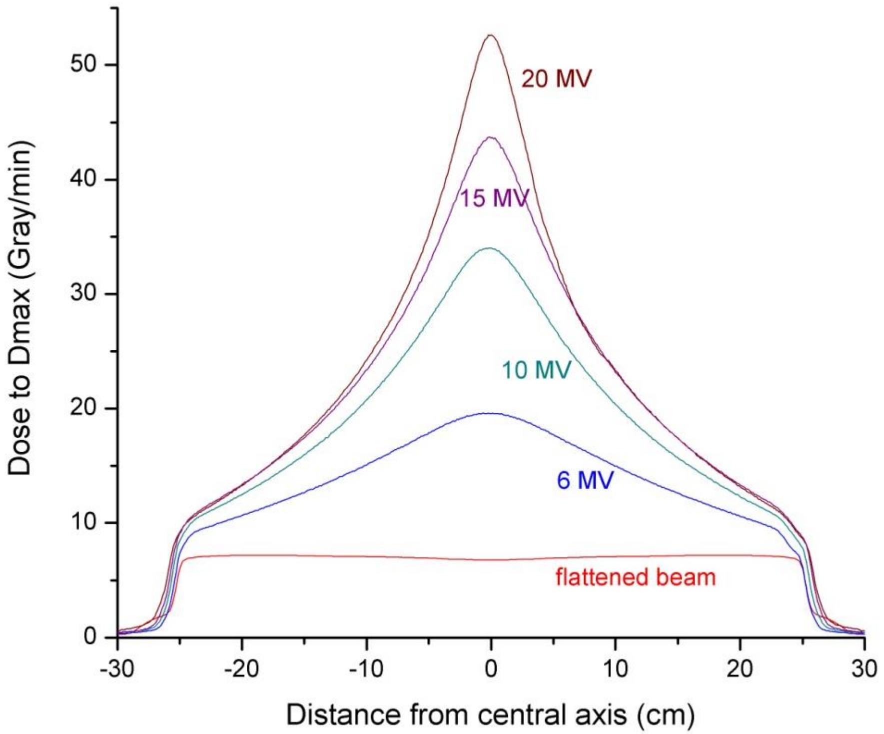

Dose
117.6
110.0 %
100.0 %
90.0 %
80.0 %
70.0 %
60.0 %
50.0 %
40.0 %
30.0 %
20.0 %
11.8 %
H
L
F
Standard
Head First-Supine


TRILOGY

Flattening Filter Free (FFF) Mode

Higher dose rates, lower scatter and out of field leakage are possible by removing the flattening filter

- Gains for IMRT, RapidArc or small field SRS
- Available in clinical mode for
  6 MV → 1400 MU/min
  10 MV → 2400 MU/min



Innovative

Transforms today's treatments

Unlocks new treatment options

Opens opportunities for SBRT treatment of the most complex cancer cases: lung, liver, kidney, pancreas and paraspinal

Opens the door to surgical candidates

Increased Performance

Intelligent

Imaging

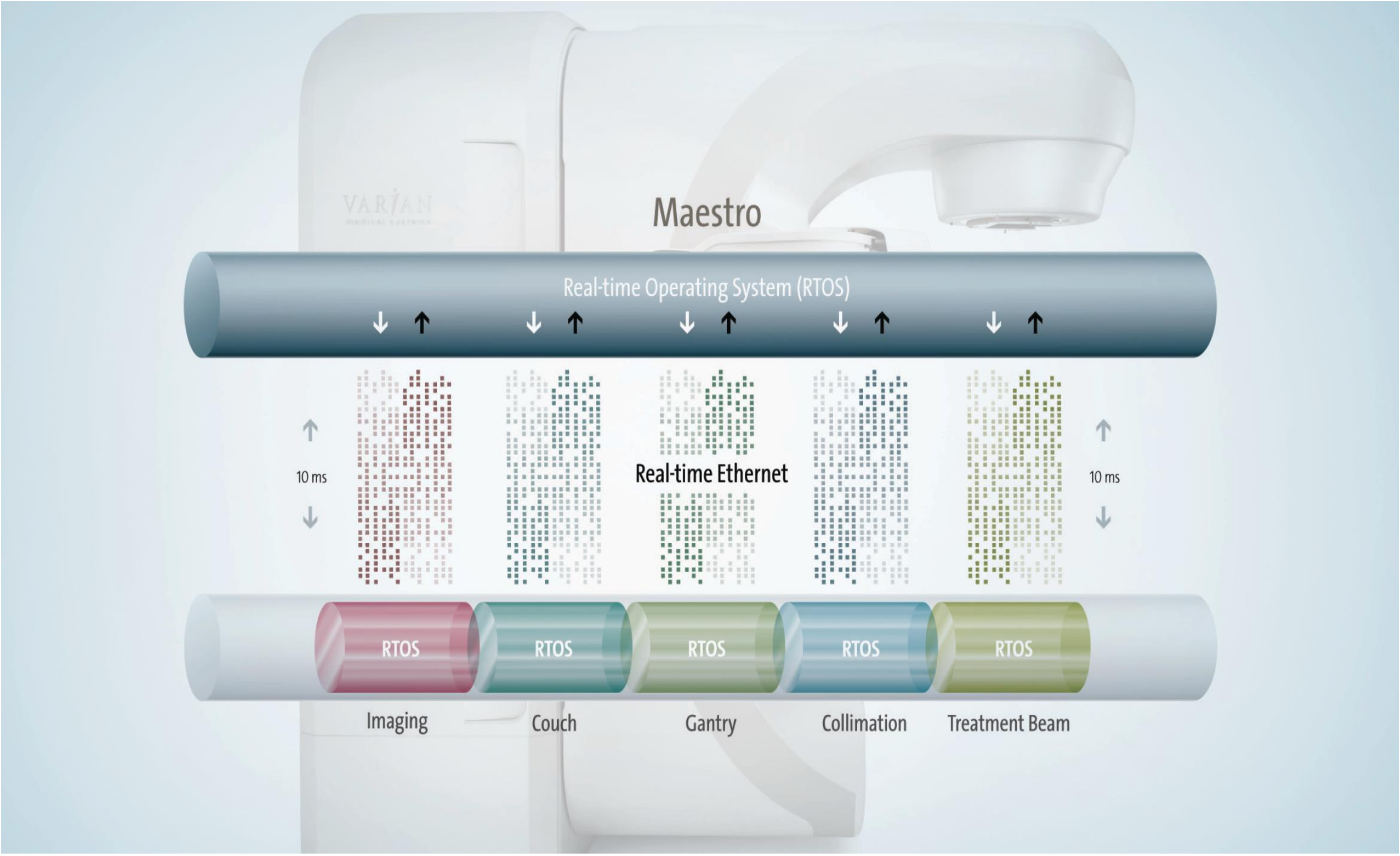
Automation

Faster treatments

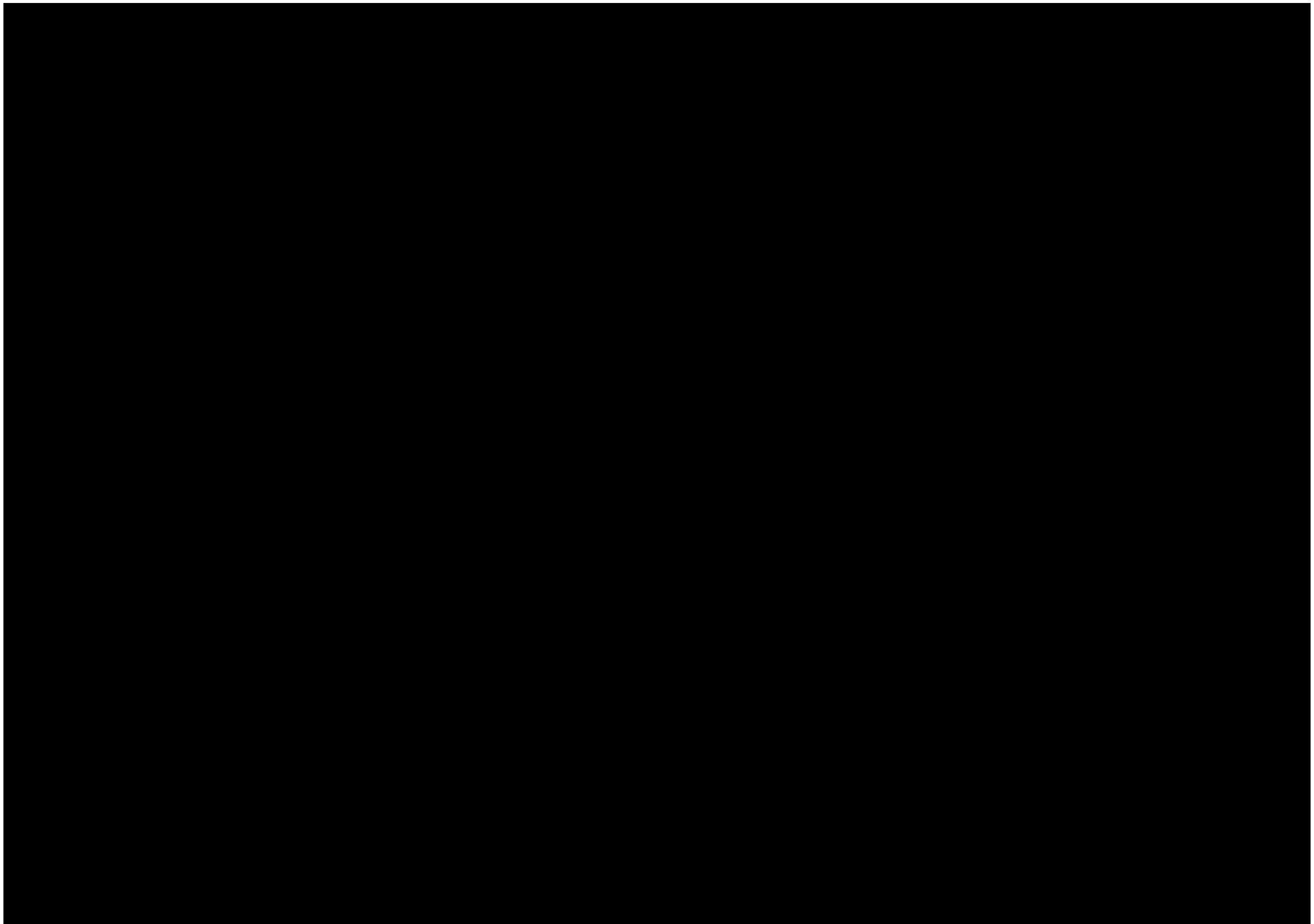
rapid IMRT

“rapider” RapidArc

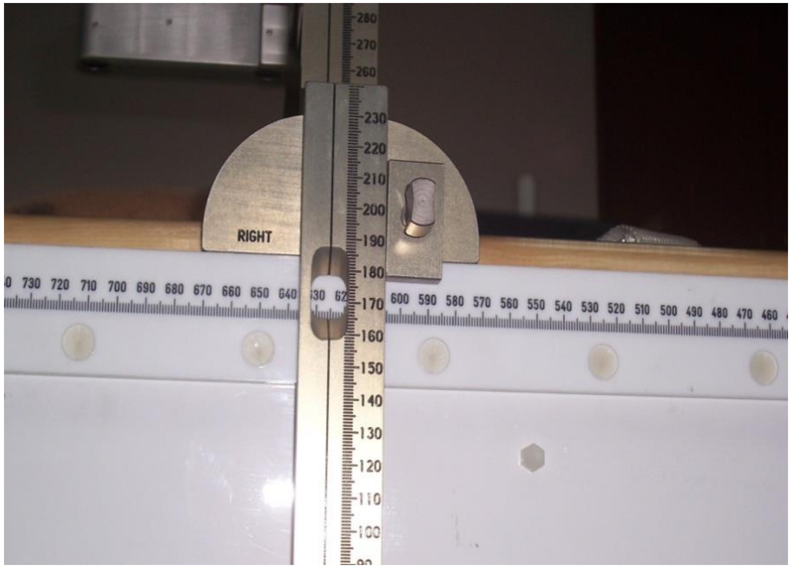
Maestro Real-time Control System



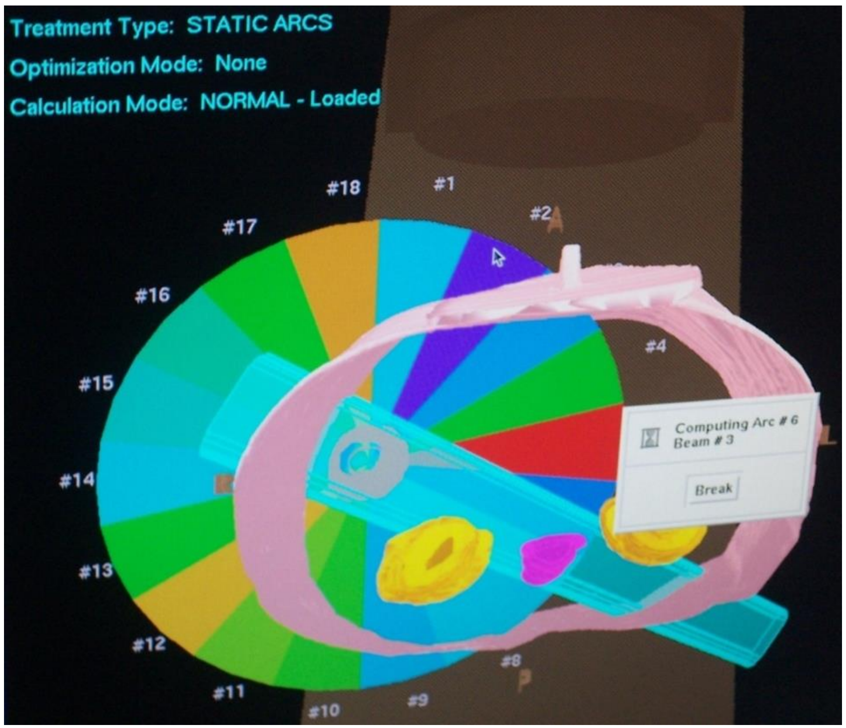
Hardware Overview - Accelerator

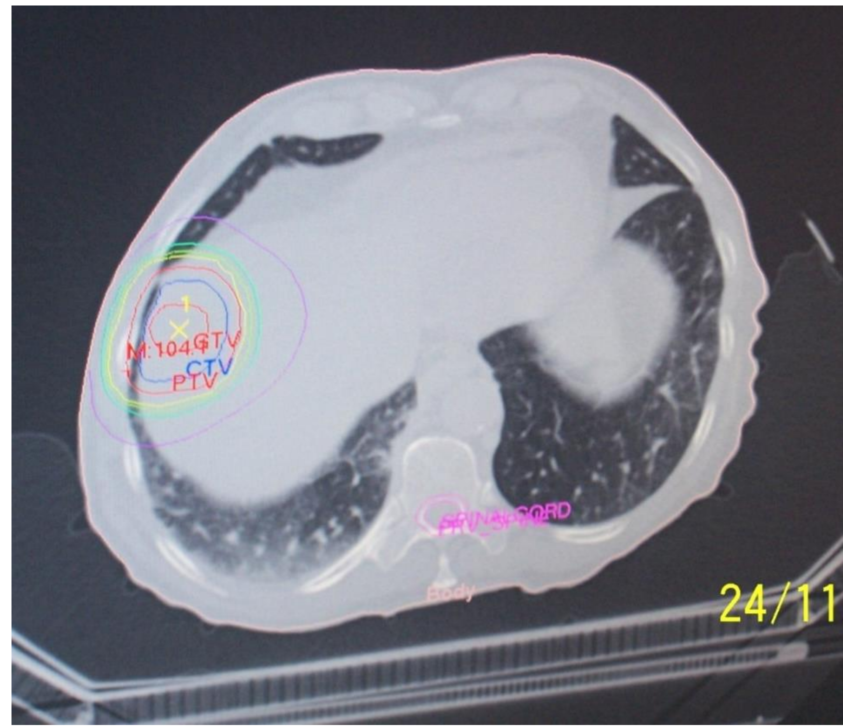


SBRT : Liver

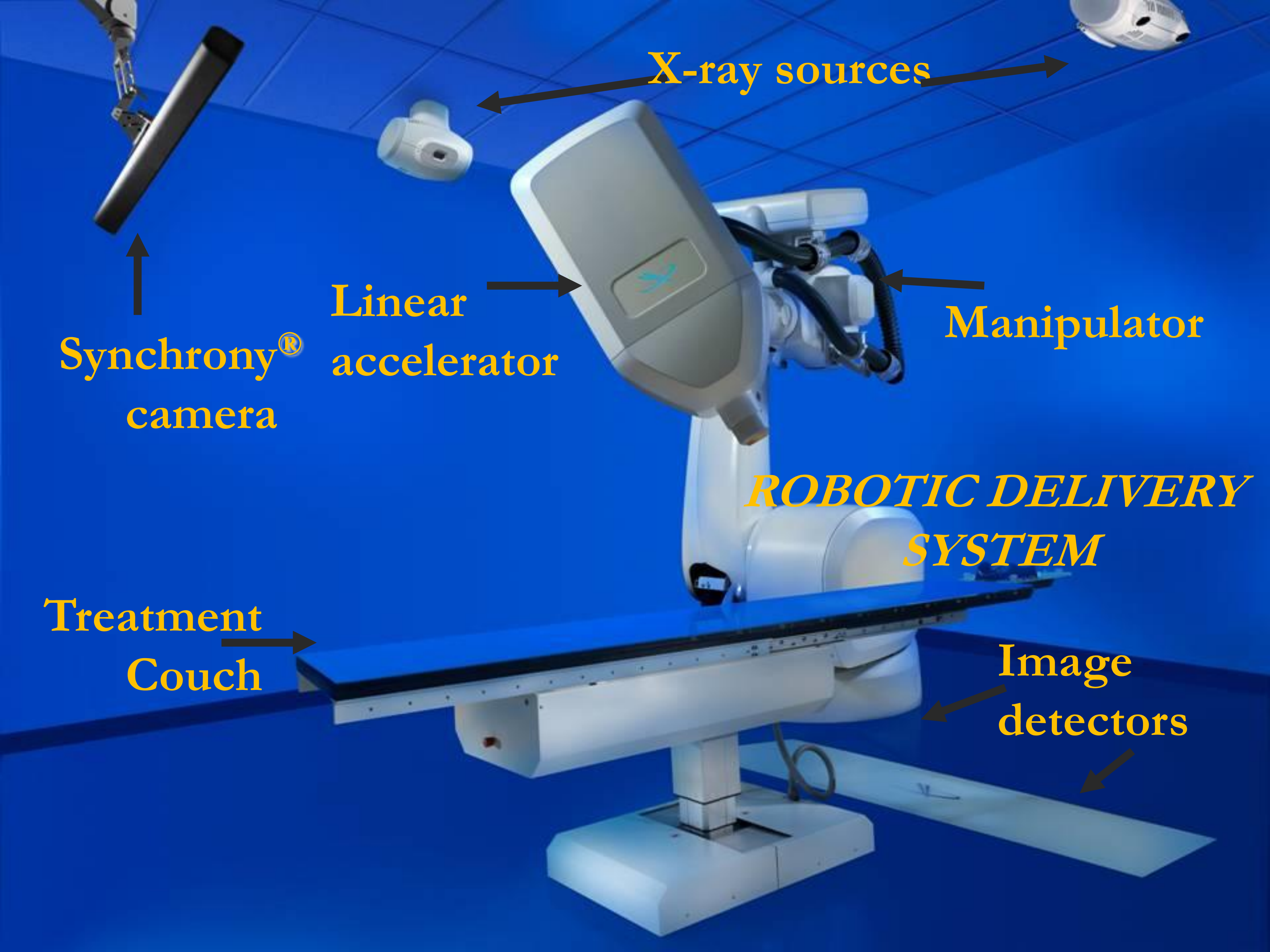


SBRT : Liver


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
M:104.1
24/11/

Robotic Radiotherapy


X-ray sources
Synchrony®
camera
Linear
accelerator
Manipulator
ROBOTIC DELIVERY
SYSTEM
Treatment
Couch
Image
detectors

Accuracy

- Sub-millimeter accuracy
- Treats all parts of the body
- Treats lesions that were previously untreatable
- So accurate, head and body frames are not required

Conformality

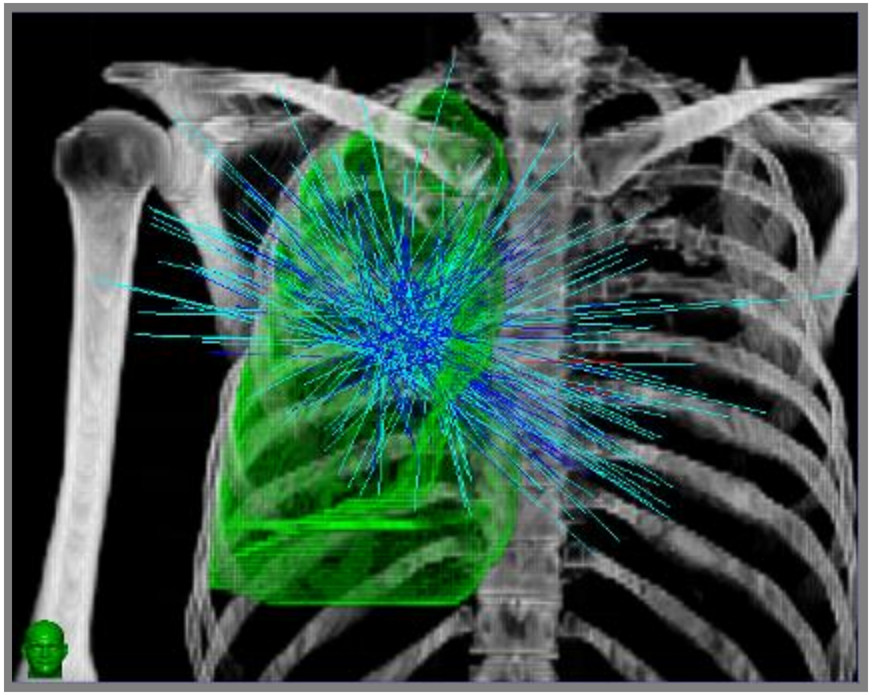
Non-Coplanar Beam Delivery, Non-Isocentric Beam Delivery

Highly collimated beams, Non-convergent beams

Automatically minimizes entrance/exit beam interactions

No patient or linac re-positioning required

Superior conformality while maximizing homogeneity



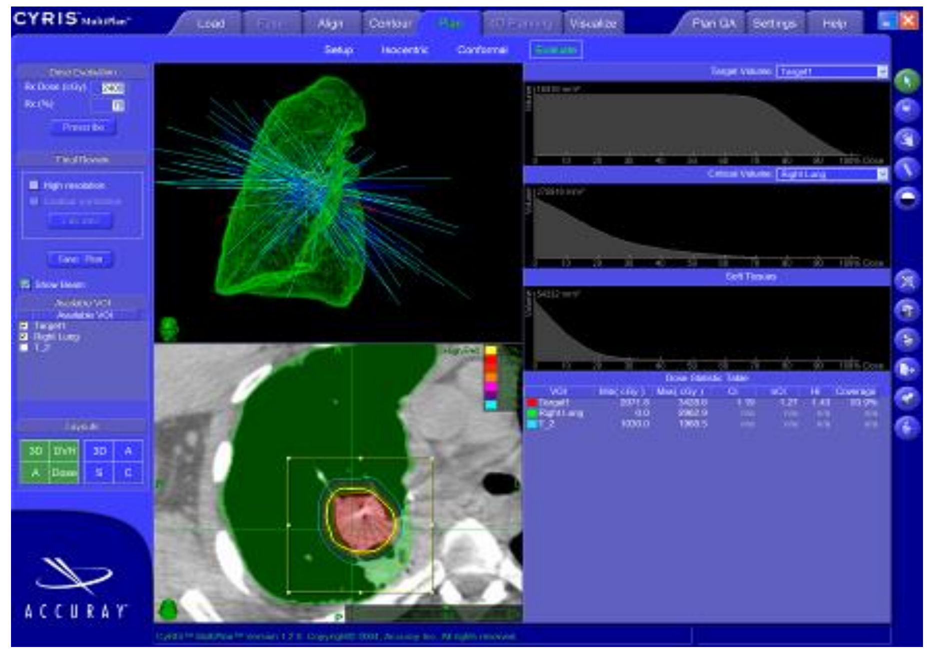
Treatment Procedure

1. Patient Consult
2. Patient Setup
3. Image Acquisition
4. Treatment Planning
5. Treatment Delivery

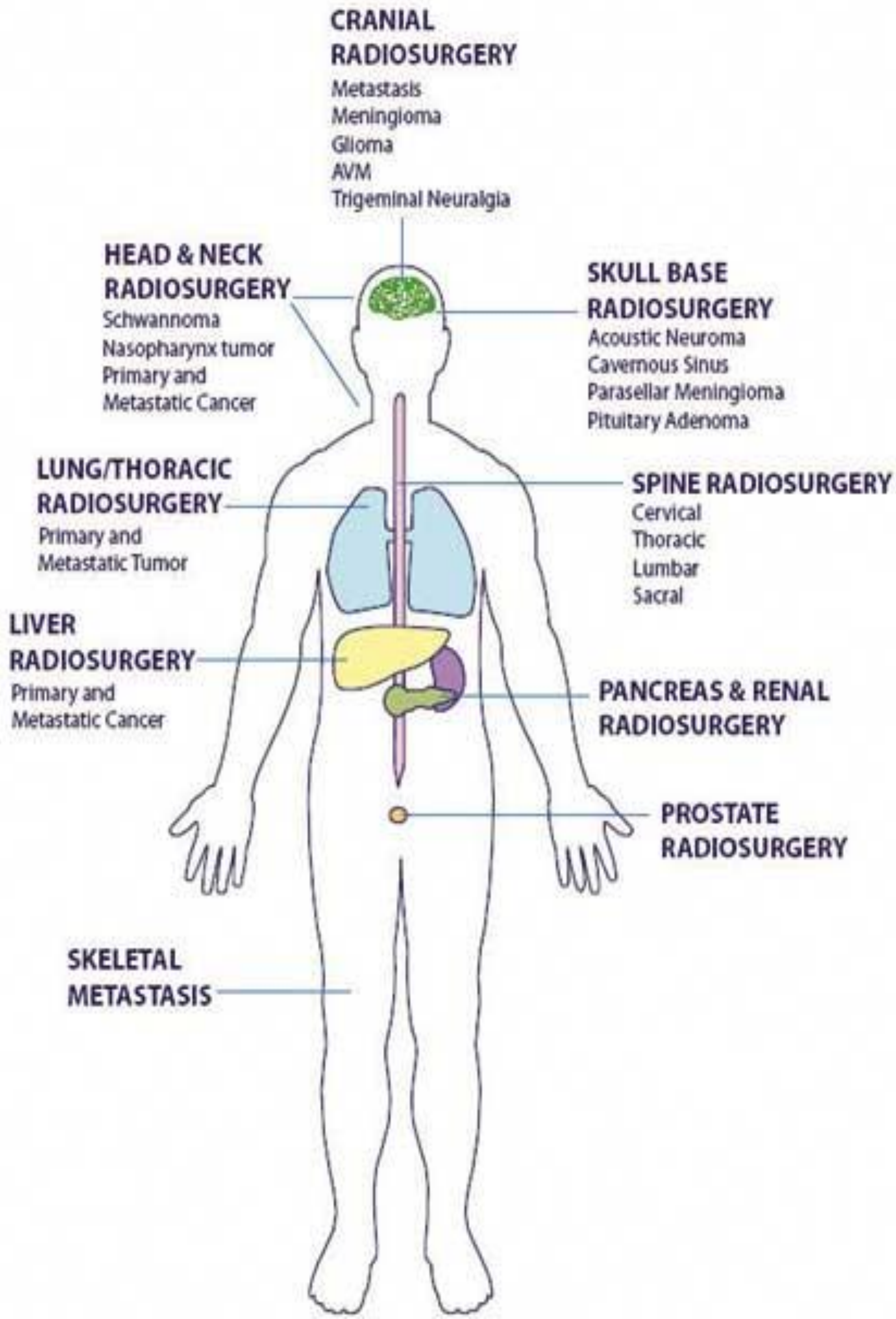
CyRIS™ MultiPlan™ Treatment Planning

Benefits

- Fast, multi-modality image fusion
- Simplified contouring
- Supports forward and inverse planning methods
- Achieves desired plan results quickly and efficiently
- Streamlines overall planning process
- Maximize the capabilities of CyberKnife System



Possible Treatment Areas

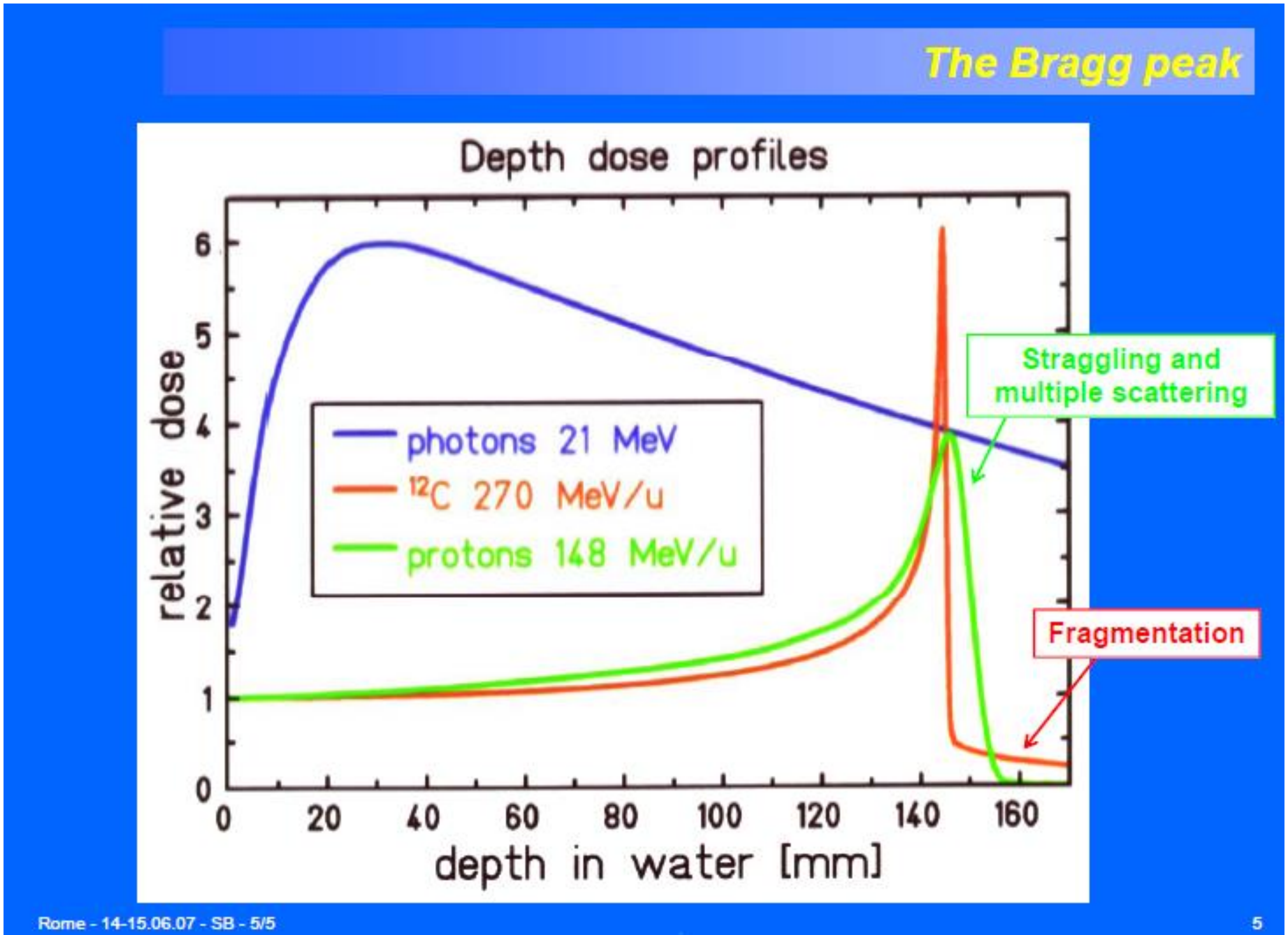


Dose/fraction		TDF equivalent Conventional
4.8 Gy/5f (24.00 Gy)		40 Gy
5.1 Gy/5f (25.50 Gy)		45 Gy
6.1 Gy/5f (30.5 GY)		60 Gy
7.5 Gy/5f (37.5 Gy)		76 Gy

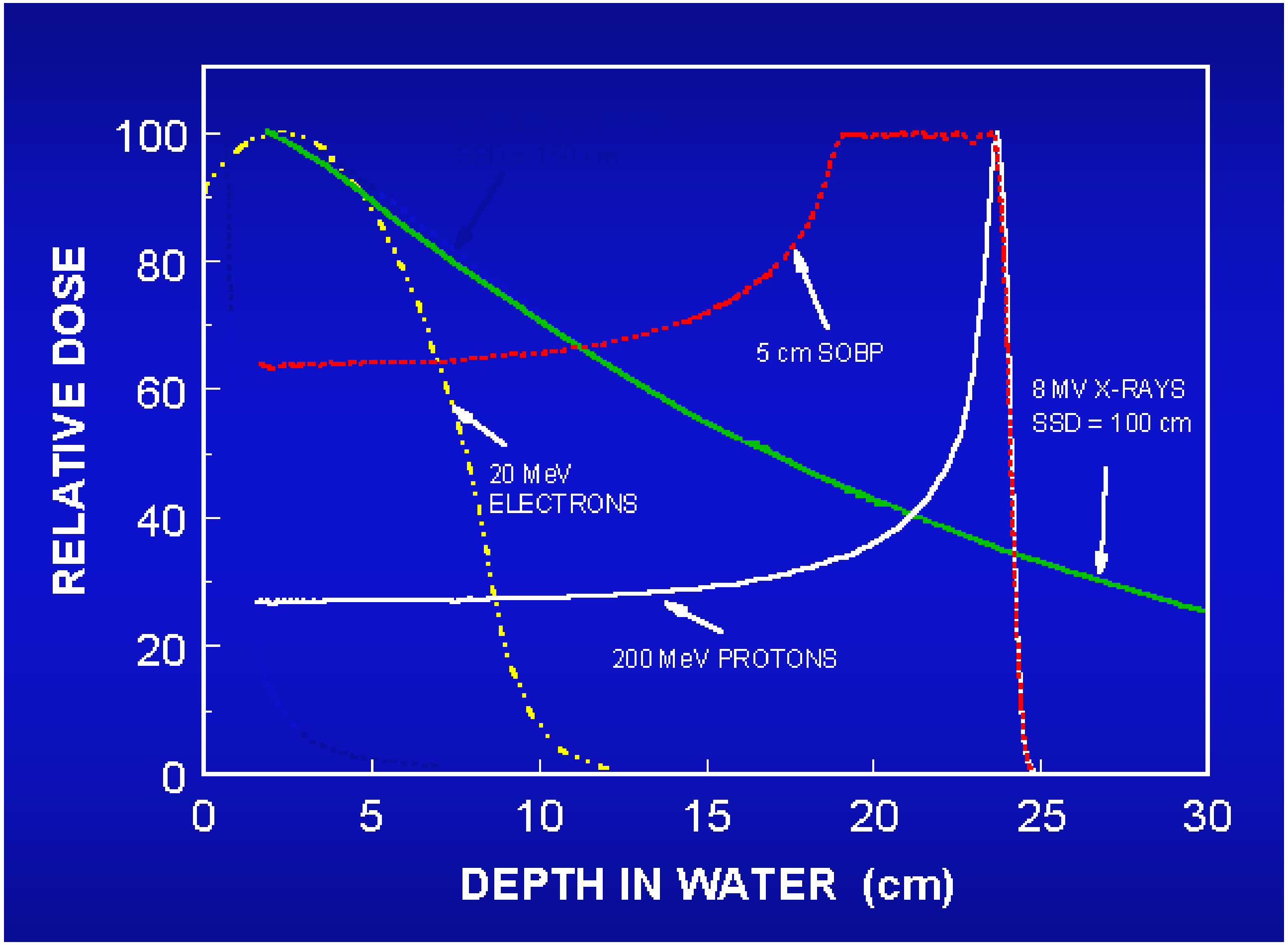
ADVANCES IN RADIOTHERAPY

PARTICLE THERAPY

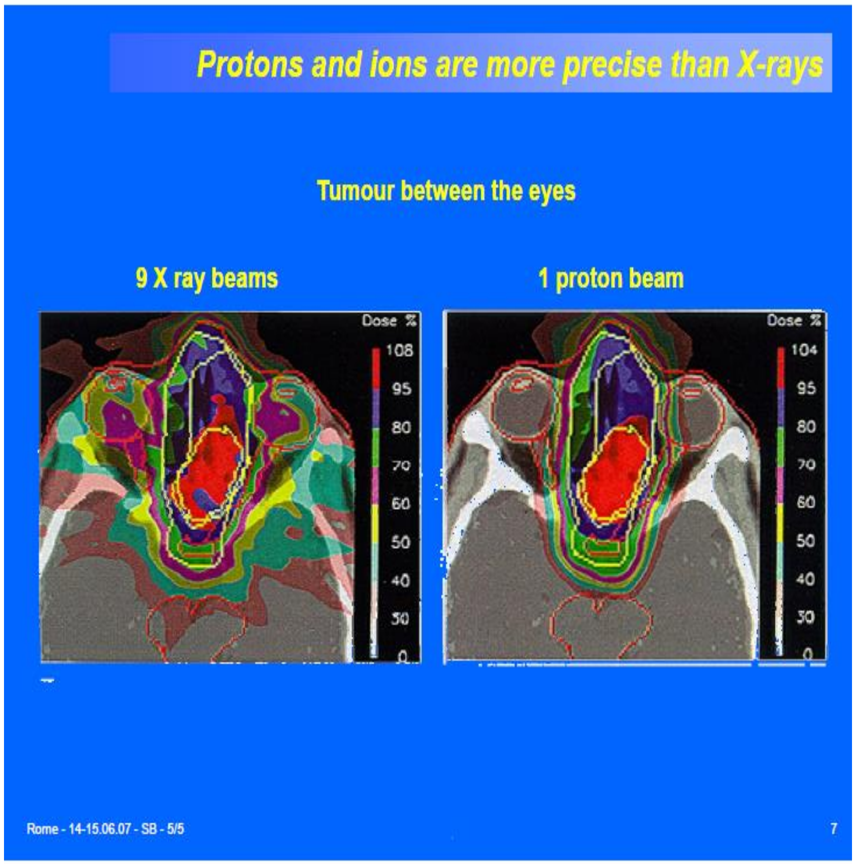
BEST FORM OF CONFORMAL RADIOTHERAPY
PARTICLE THERAPY

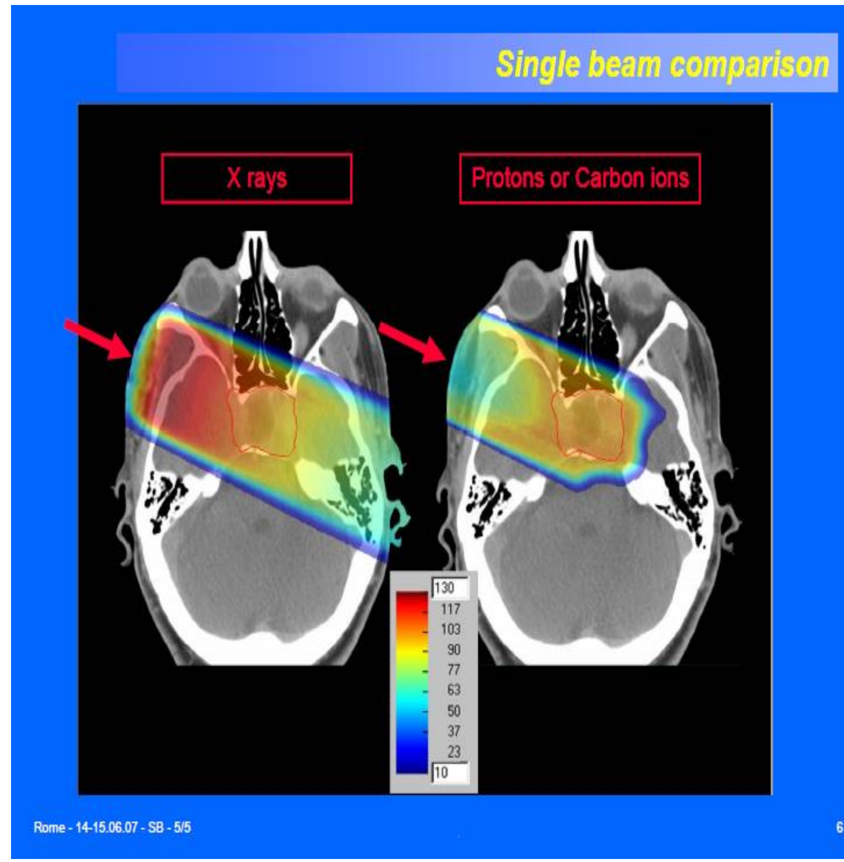


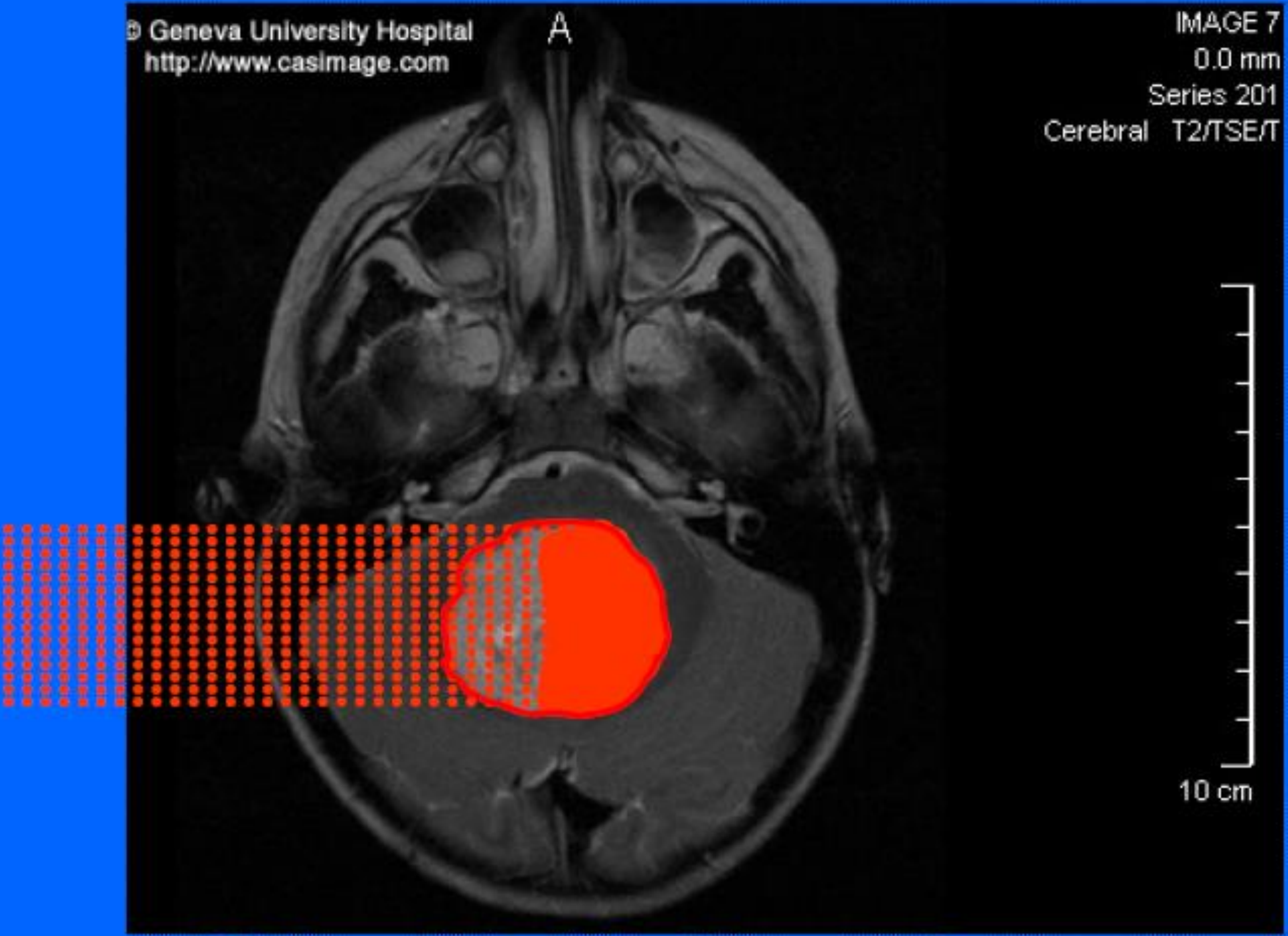
PROTON THERAPY



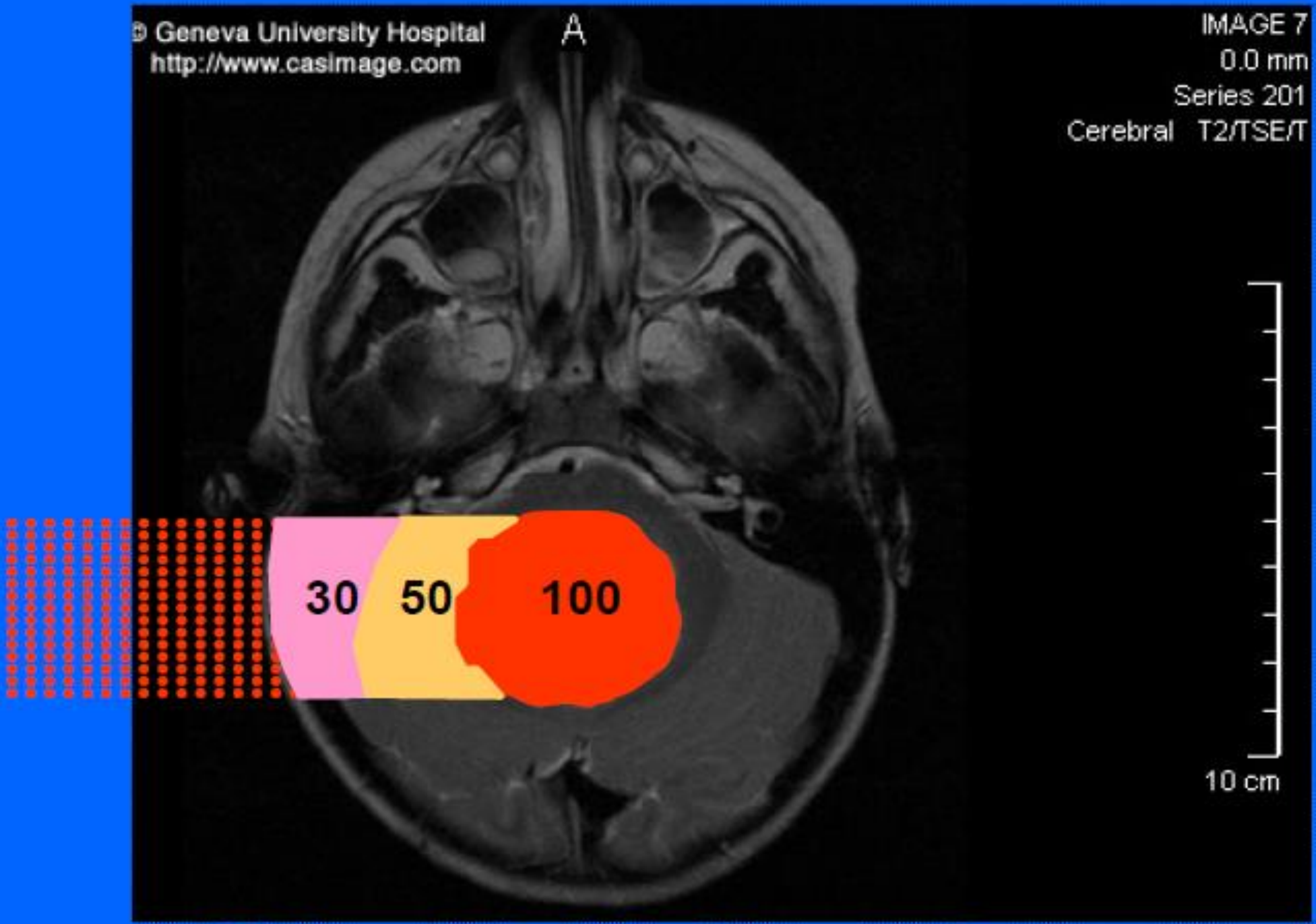
PARTICLE THERAPY



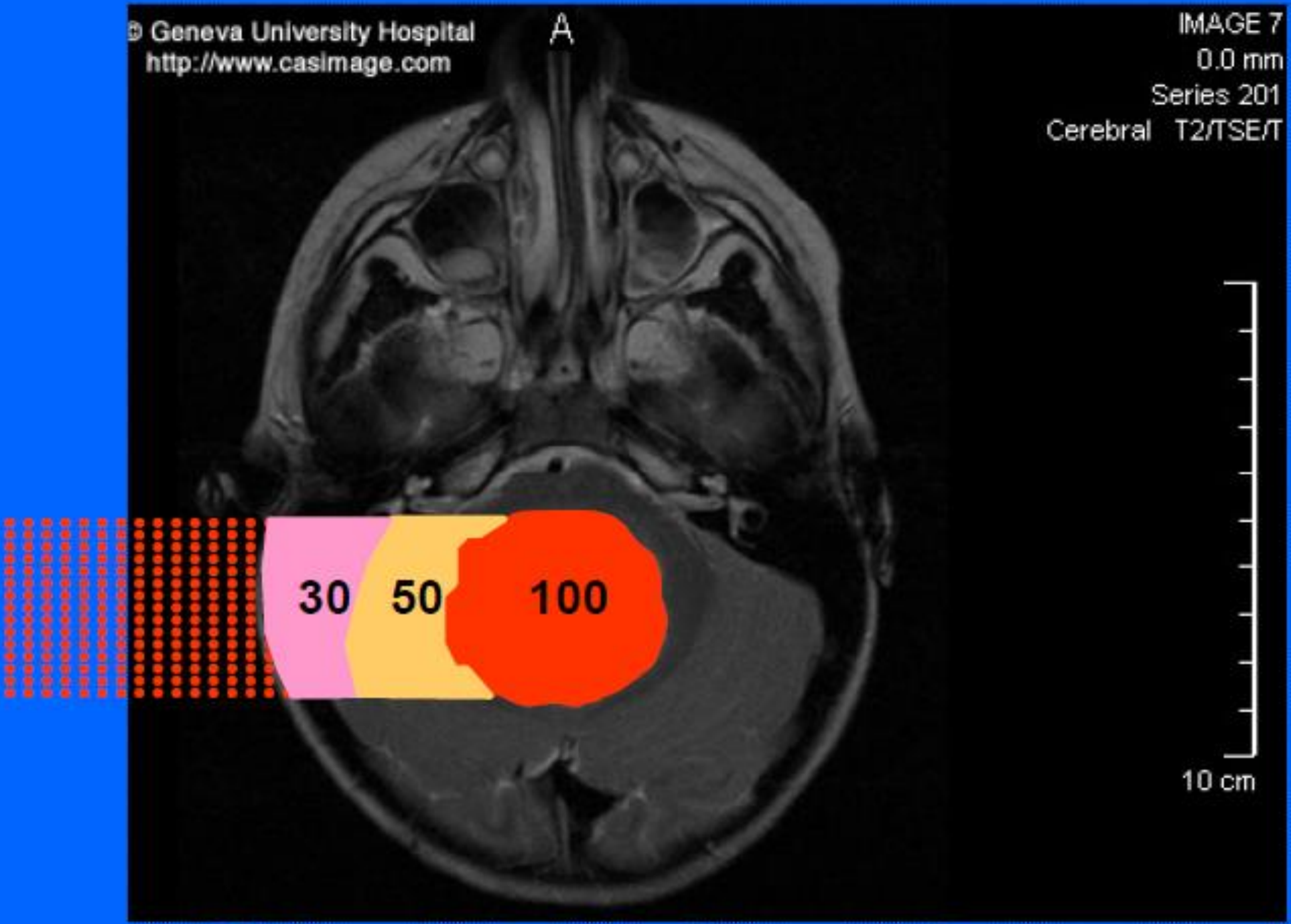




High precision RT with proton beams

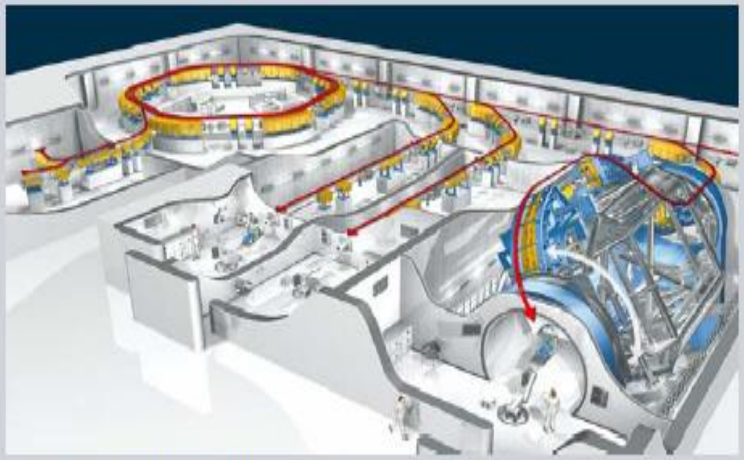


High precision RT with proton beams

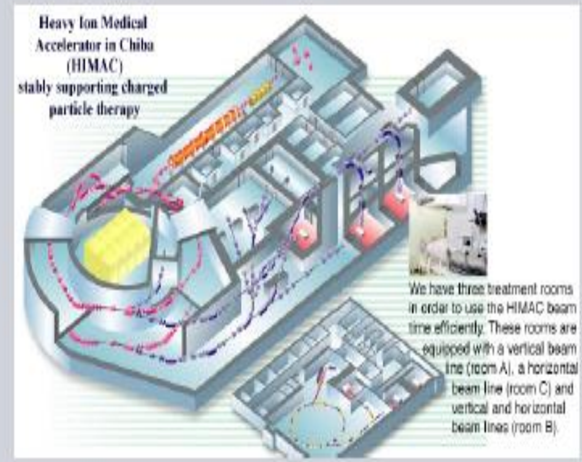


High precision RT with proton beams

PREMIER PROTON THERAPY CENTRES



University of Heidelberg, Germany / GSI and Siemens



NIRS Chiba, Japan / Mitsubishi, Hitachi, Sumitomo

MD Anderson Houston, USA / Hitachi

PSI
Villigen,
Switzerland /
Varian-Accel

MGH Boston, USA / IBA

Current Trends in Brachytherapy

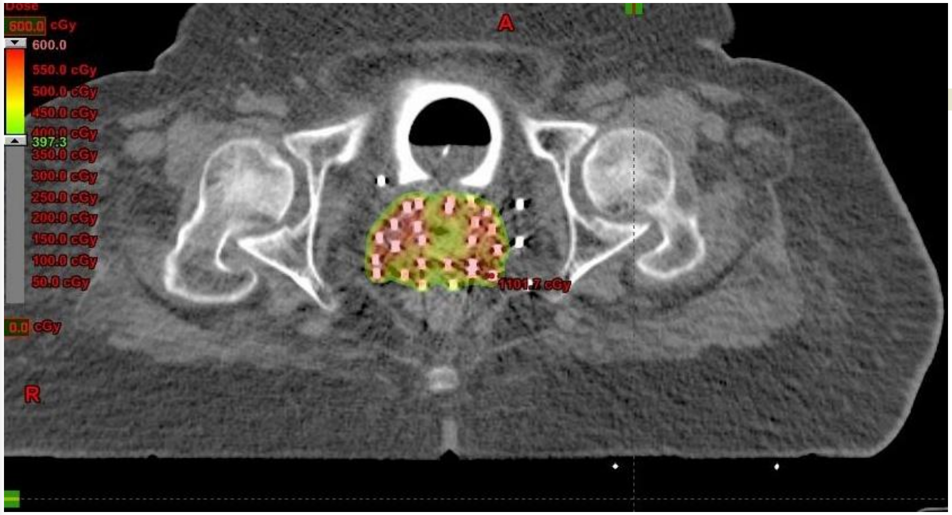
- Recently established practices
  - "Image-based" BTx: design and post-insertion evaluation based upon correlating 3D dose distribution and anatomy
  - "Image-guided" BTx: intra-op imaging to help place sources in correct anatomic location
- Clinical developments
  - TRUS-guided prostate BTx
  - Increasing use of CT-guided interstitial HDR
  - Increasing use of MR
  - Replacement of LDR temporary by permanent seeds or HDR

Paradigm Shift

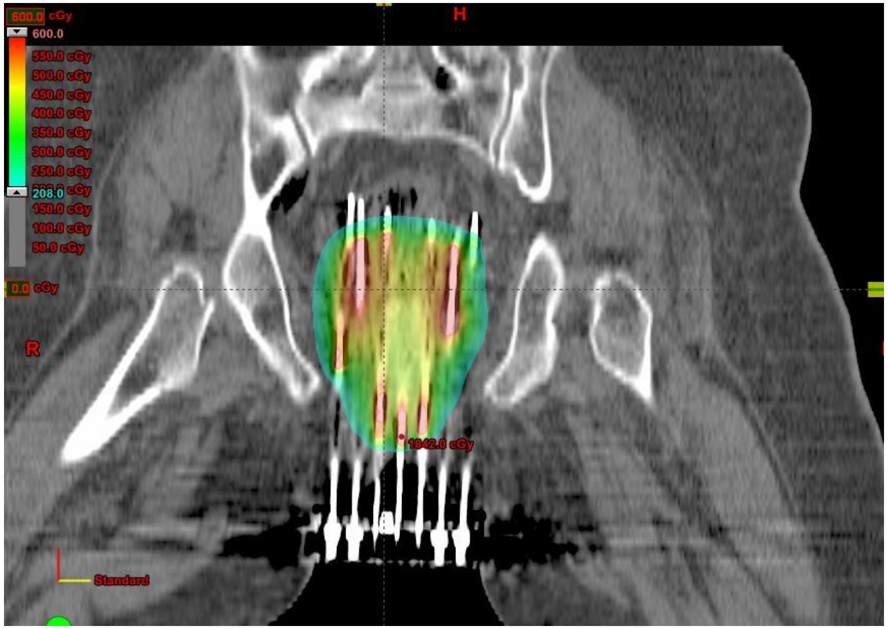
- The GYN GEC ESTRO group has developed and promoted a novel systematic approach with the integration of 3D sectional imaging (MRI (CT)) into the procedure of application and medical-physical brachytherapy treatment planning.
- Aim of this method is to enable an individualized adaptation of dose distribution to a target at high or intermediate risk for recurrence (HR CTV/LR CTV) and to the adjacent organs at risk.
- During the last years the MRI-based approach has gained in importance and has increasingly replaced the well established traditional x-ray based methods.

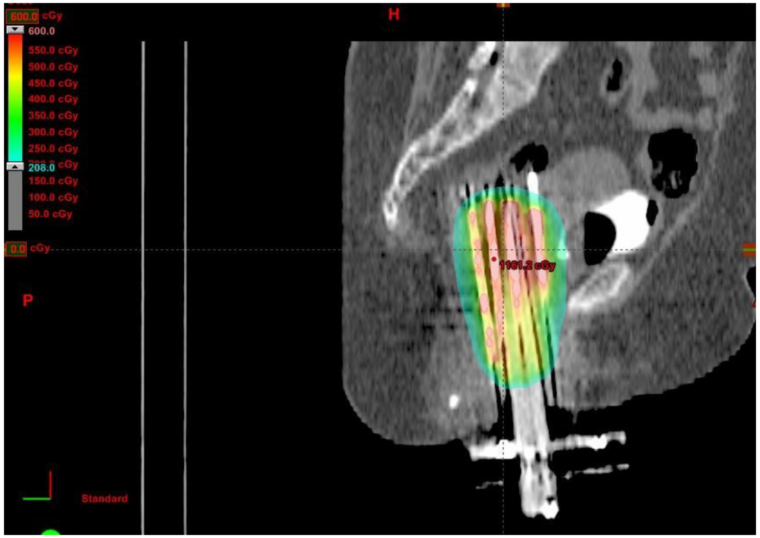
Image Guided Brachytherapy

- The GEC-ESTRO and American Brachytherapy Society groups have recently made recommendations on the use of 3D image-based treatment planning in gynecological brachytherapy.
- Applicators compatible with both CT and MR imaging modalities are essential for IBGT.
- Applicators – Titanium



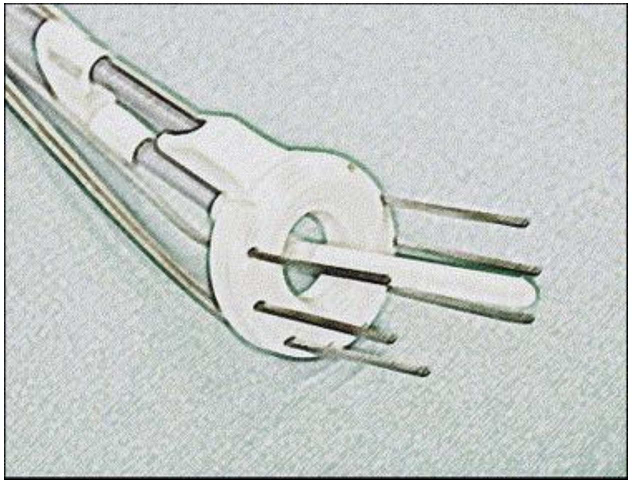
CT Based – MUPIT

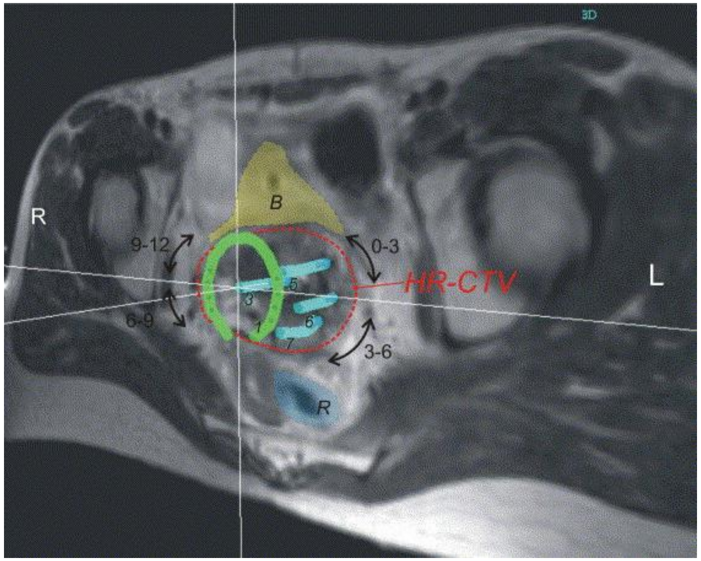




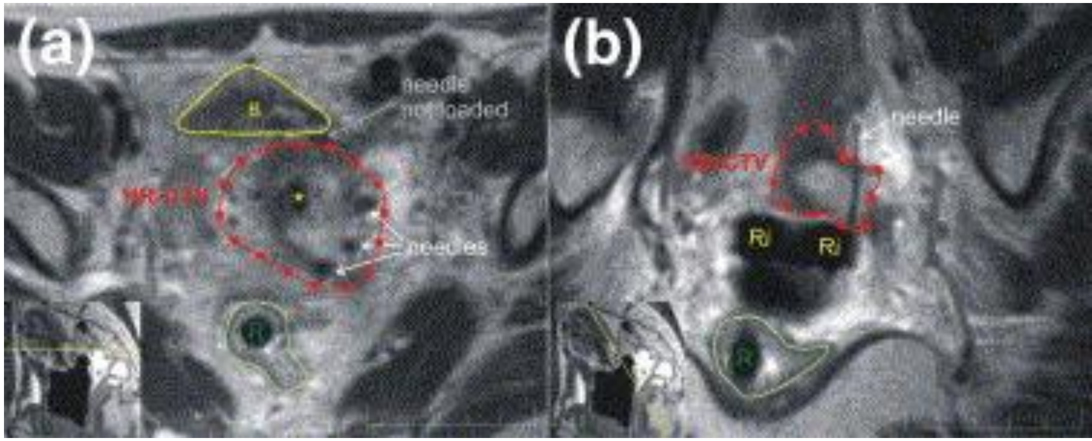
Promising Technologies in Cervix Cancer

- Image Guided Brachy: MR-Based (RTOG 0417)
  - Point A was not designed for dose prescription

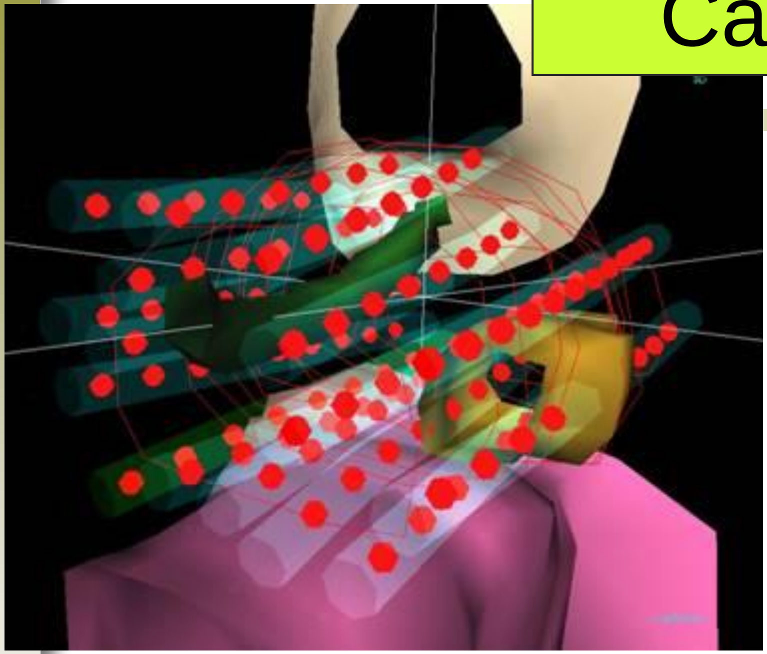


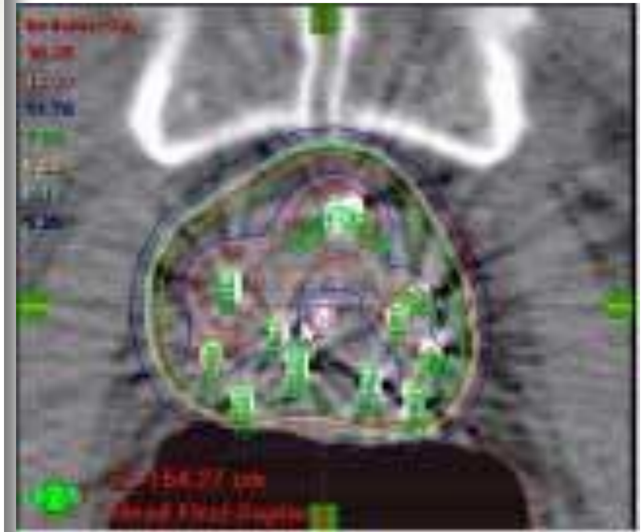
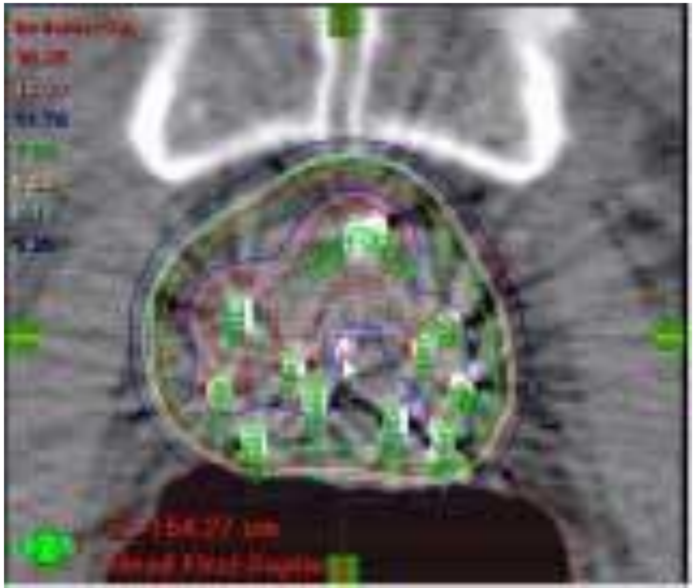


Dimoupoulos *et al* IJROBP 66(1):83, 2006

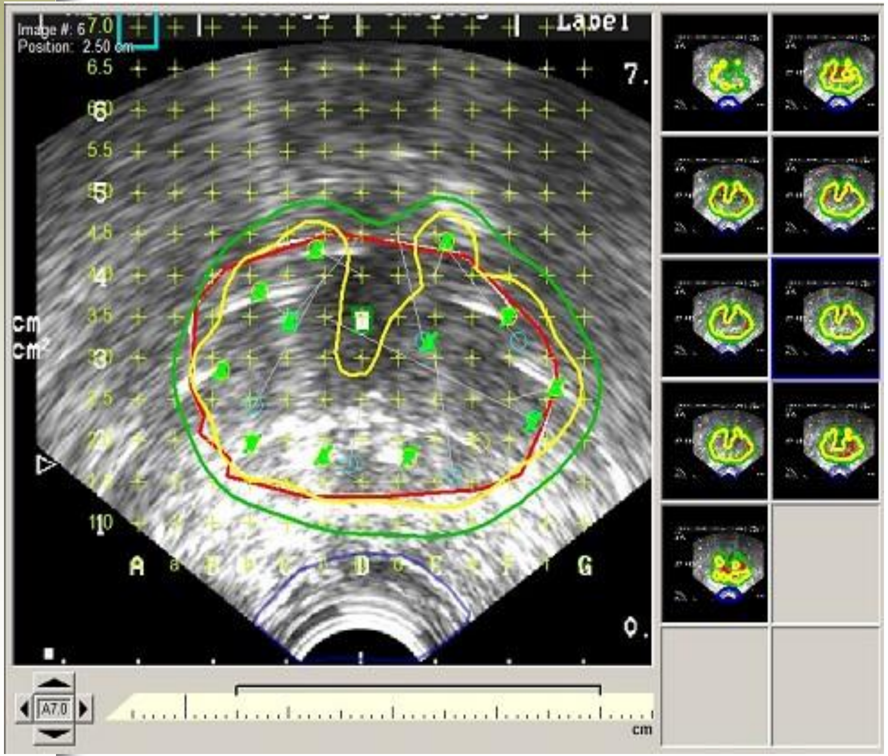


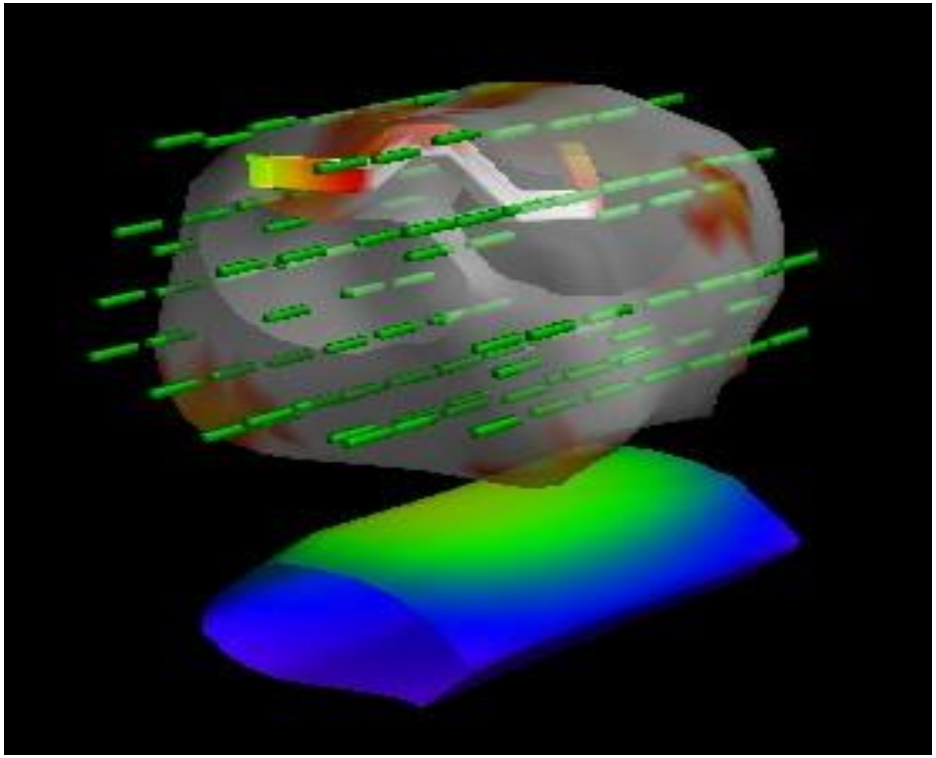
Ca Prostate



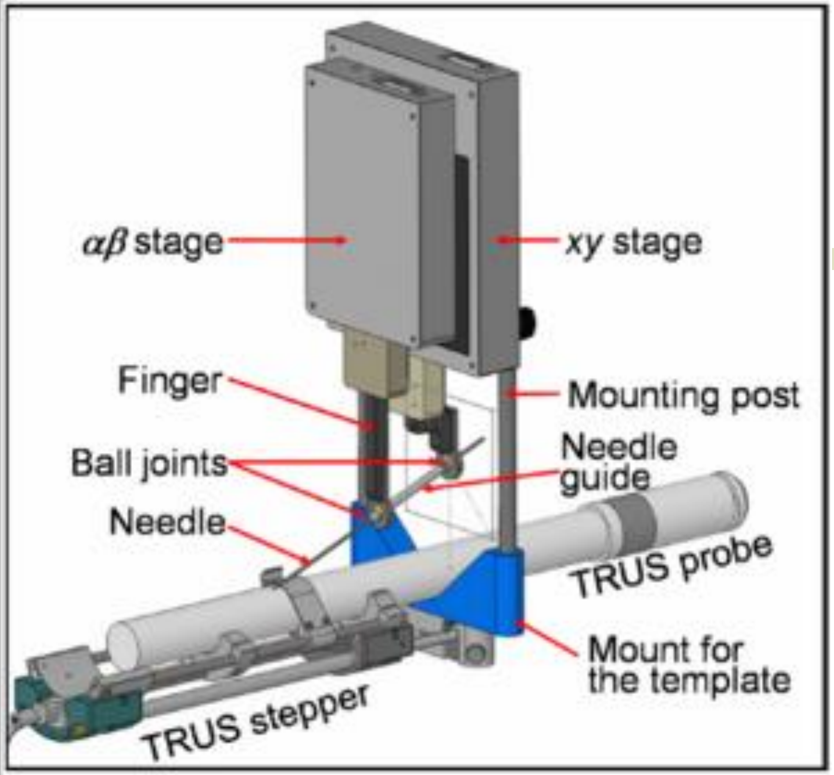
Prostate Seeds Implant



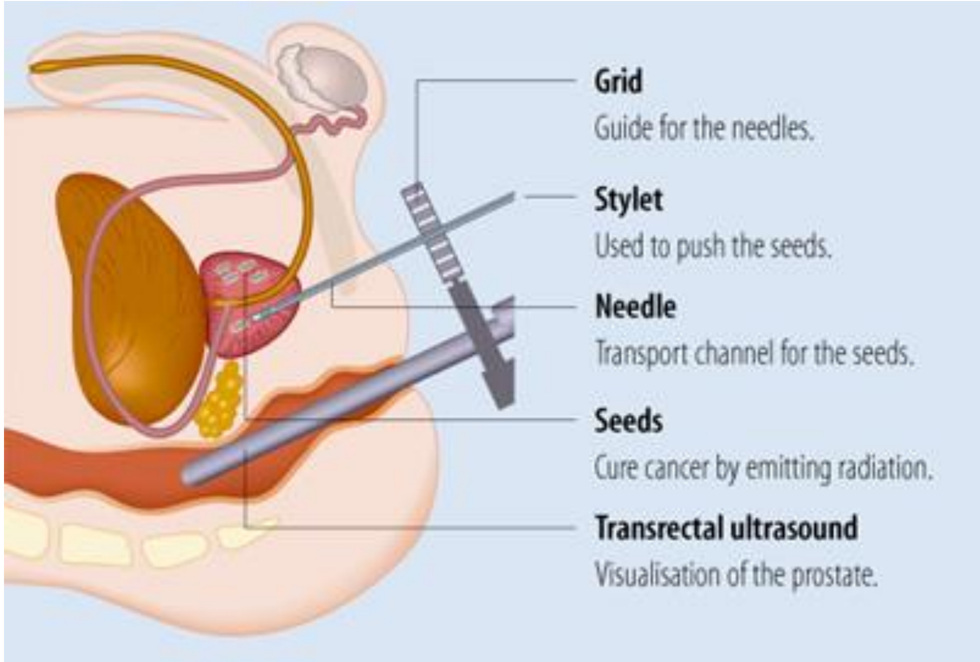


Permanent Seed Implant – Brachytherapy

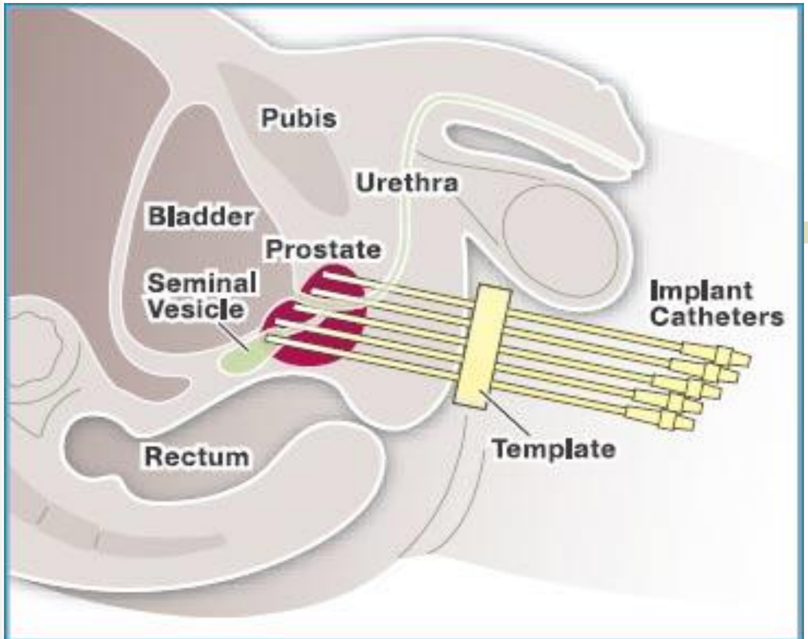
1. Low Risk → Permanent Brachytherapy alone
2. Intermediate Risk → EBRT (40 – 50 Gy) + ADT + Brachy
3. Iodine 125 / Palladium 103
4. Preplanning on previous day
5. Monotherapy – 145 Gy for I-125 & 125 Gy for Pa-103
6. EBRT (40-50 Gy) → 110 Gy I-125 & 100 Gy for Pa-103
7. Advantage : Short Duration
8. Not in INDIA

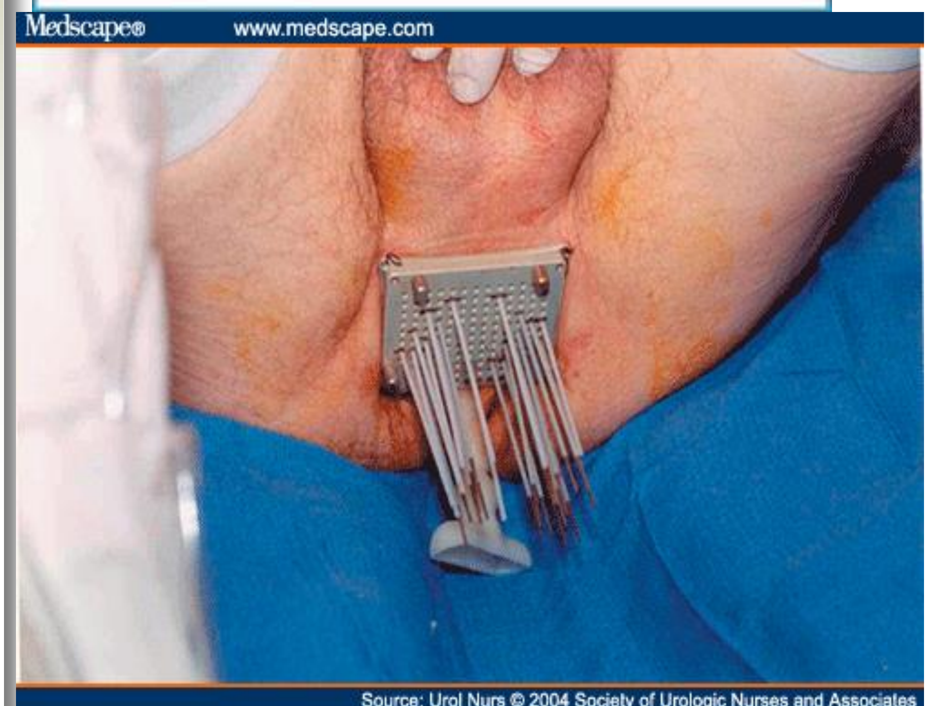


Template with USG probe

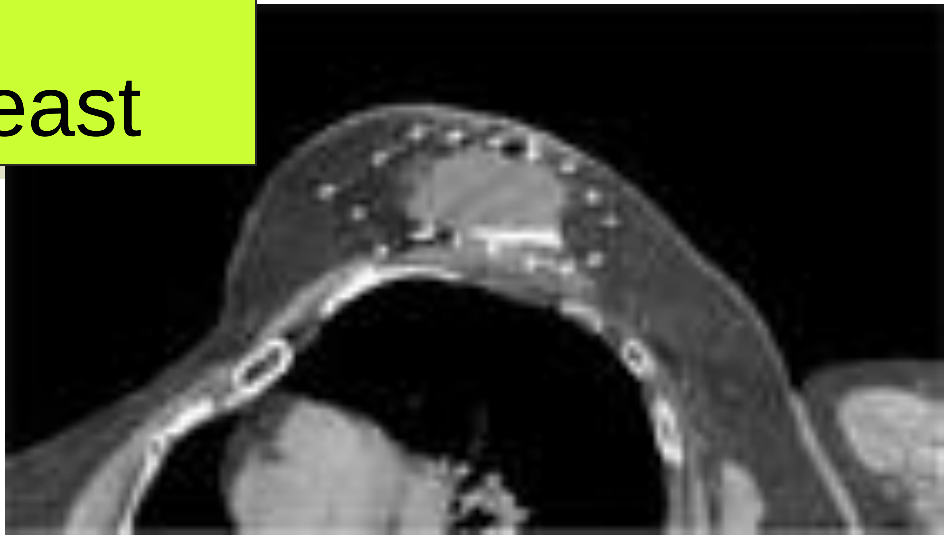


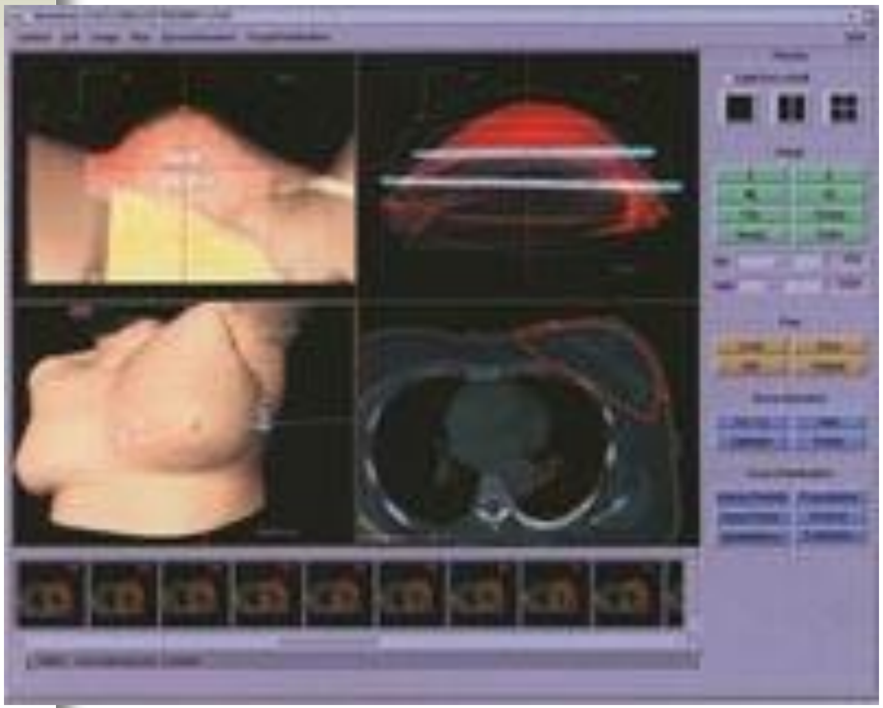
Temporary Implant

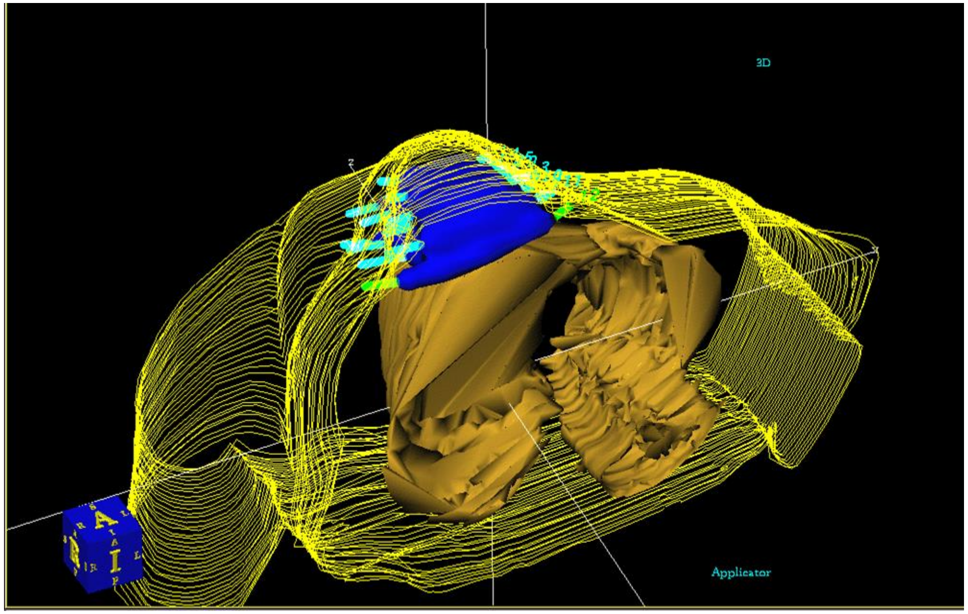




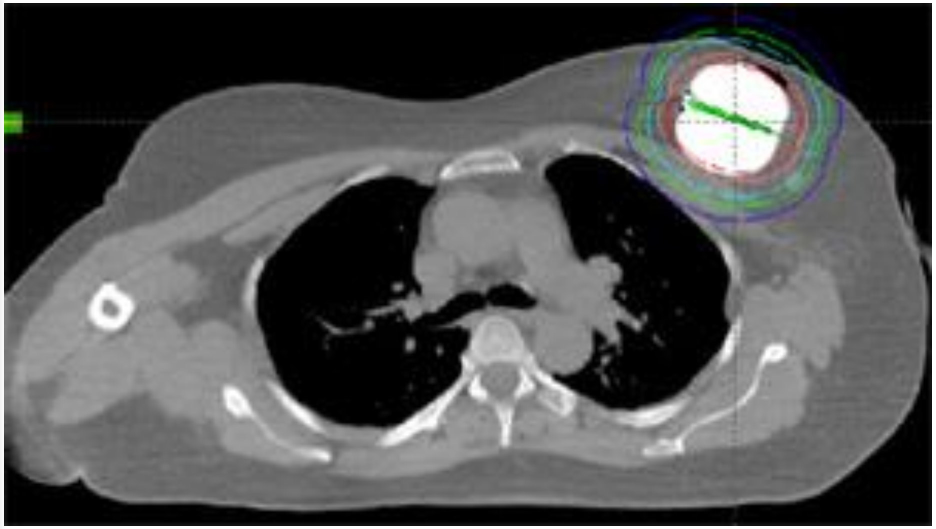
Ca Breast

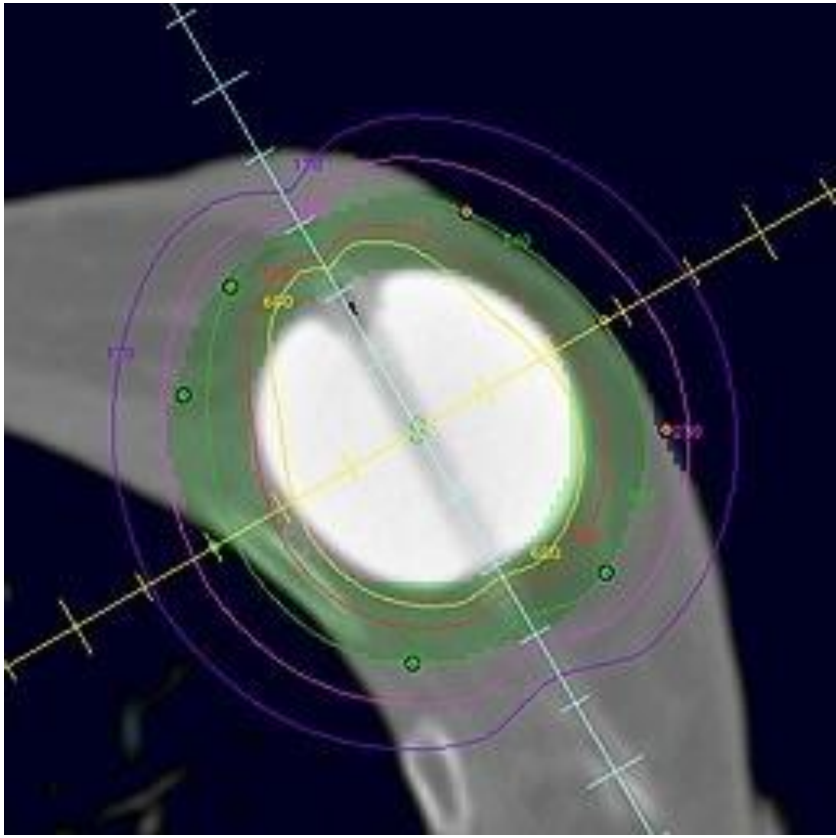






Mammosite





INTRA OPERATIVE RADIOTHERAPY

- Intraoperative Single Dose Radiotherapy delivered with the INTRABEAM System is supported by experience gained from over 10 years of clinical experience.
- INTRABEAM radiotherapy delivered as a single definitive treatment has been effectively introduced through an internationally, randomized controlled clinical trial, comparing a single dose of radiation given intraoperatively versus conventional external beam radiotherapy in women with early breast cancer.

- INTRABEAM’s platform flexibility expands beyond traditional radiation therapy systems, requiring no structural infrastructure modifications or specialized radiation protection.

- Without the limitation of traditional radiation treatment rooms, INTRABEAM Radiotherapy increases control in treatment, delivery and site-of-service, providing a one-of-a-kind radiation treatment option as unique as the patients you treat.

Low Energy X-rays

- The INTRABEAM radiation source accelerates electrons with a maximum voltage of 50 kV onto a gold target. It is here that the low-energy X-ray radiation is generated and then emitted isotropically, penetrating the tissue to a depth of about 1-2 cm. Published dosimetry results confirm the quality and constancy of the radiation field.

Future of Brachytherapy

- Thermo – Brachytherapy
- Brachy – Robotics