Physics associated with conformal radiation
- An overview

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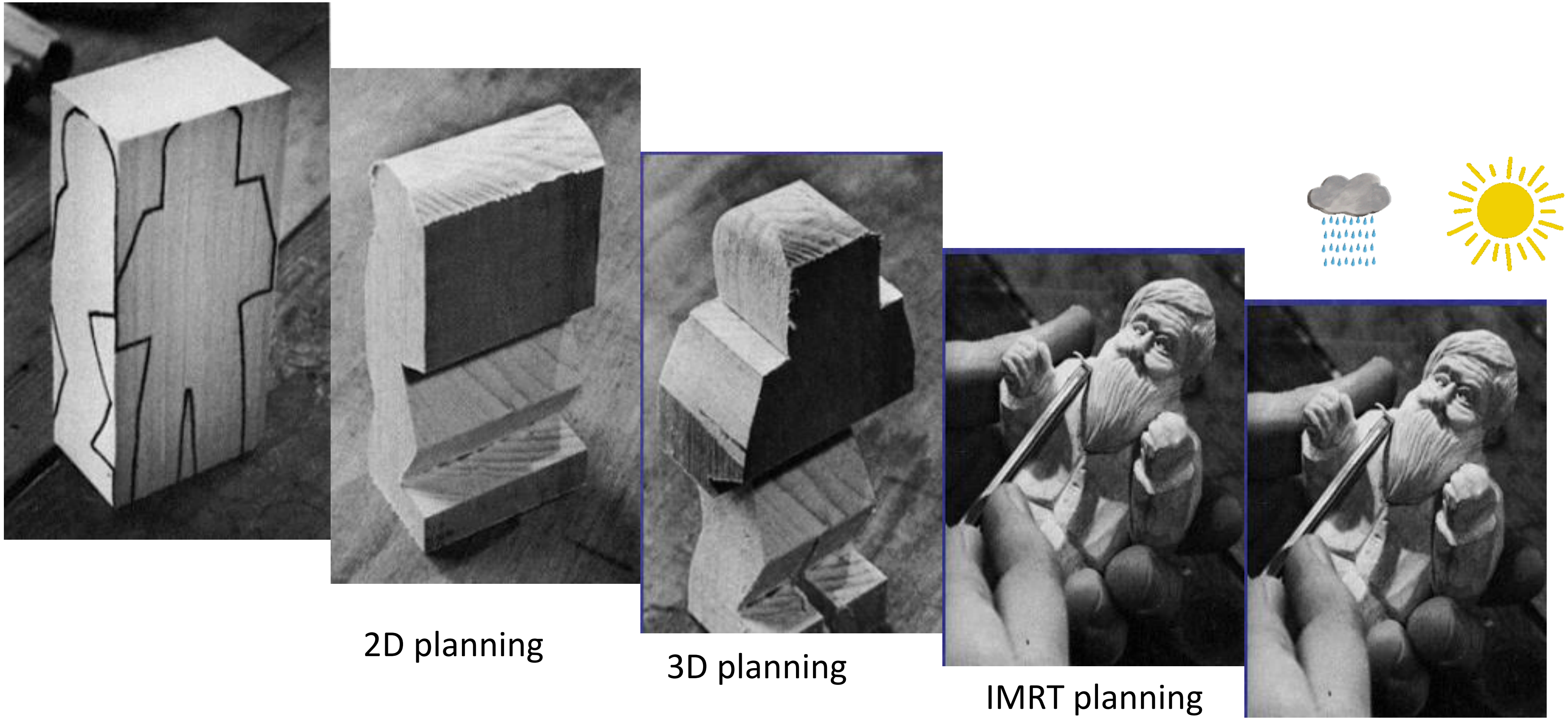
The evolution of treatments



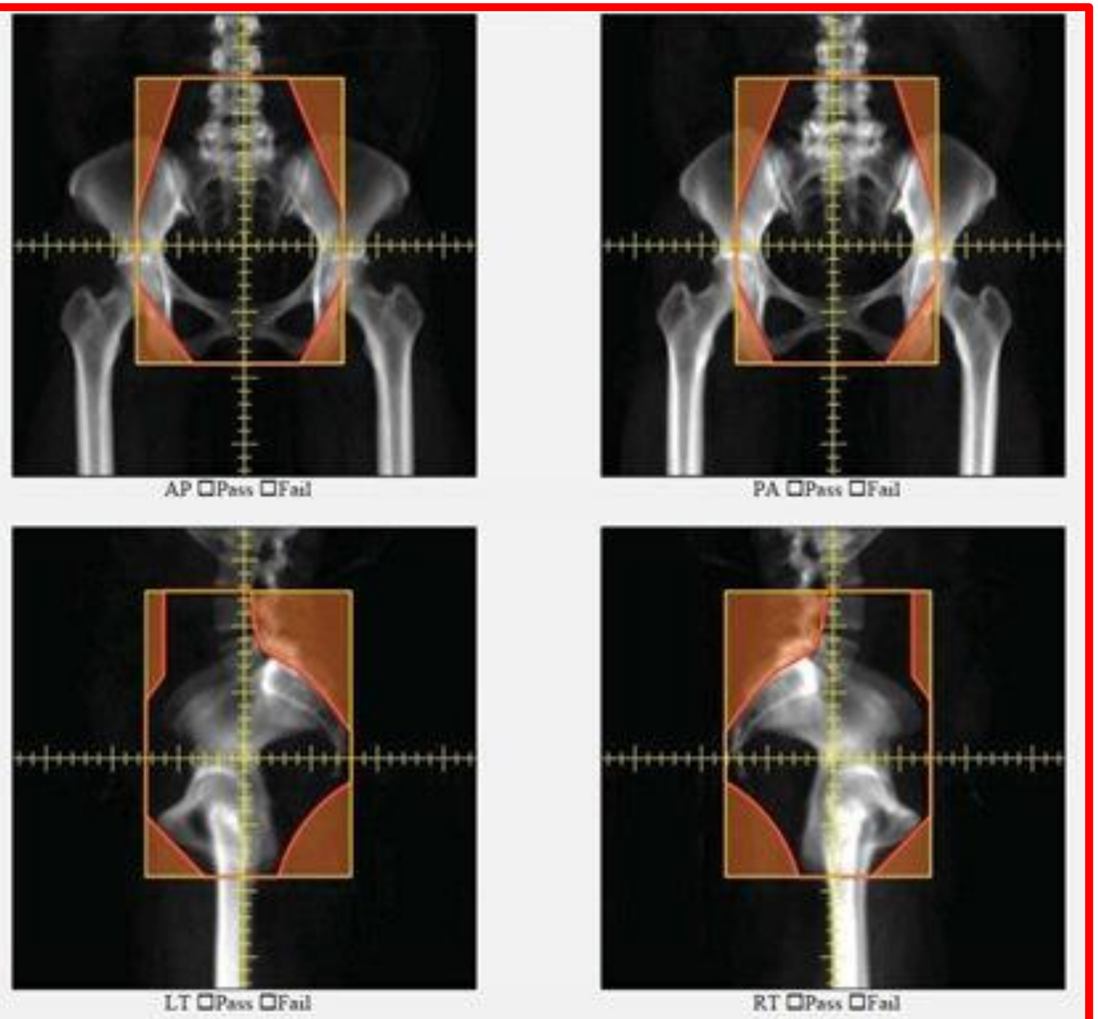
2D planning

3D planning

IMRT planning

Adaptive planning

The era of 2D Radiotherapy!



- Based on surface anatomy or x-rays
- Box fields
- Conformality achieved with putting custom made blocks and wedges

Move to 3D treatments: What all changes??

- Shift from bony landmarks to 3 dimensional structures for tumour volumes

Imaging
-CT/MRI/PET

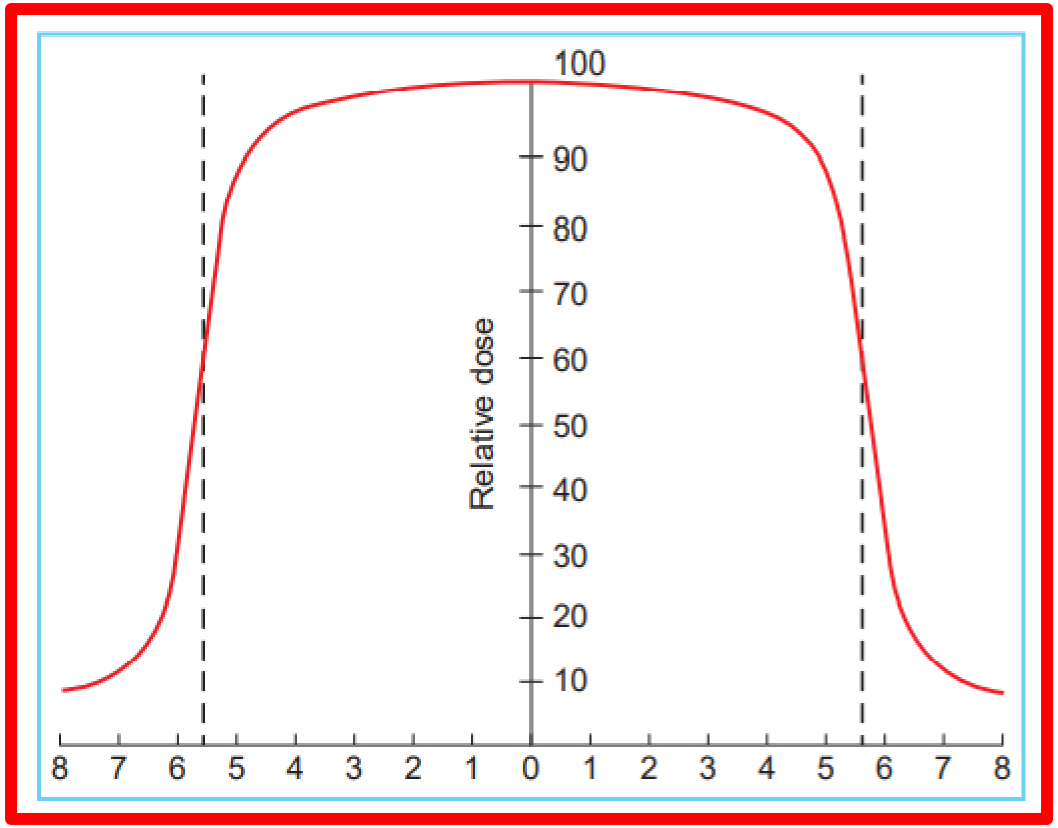
→ **Registration**
-Rigid/Deformable

→ **Segmentation**

→ **Planning and plan evaluation**

- Multiple beams
- Beam angles
- Beam apertures; MLCs
- Beam weights
- Beam modifiers (wedges and compensators)

What doesn’t change?



Beam profile remains consistent

- In 2D radiation and 3DCRT, radiation beams are of uniform intensity across the field (within the flatness specification limits).

- Occasionally, wedges or compensators are used to modify the intensity profile to offset contour irregularities and/or produce more uniform composite dose distributions.

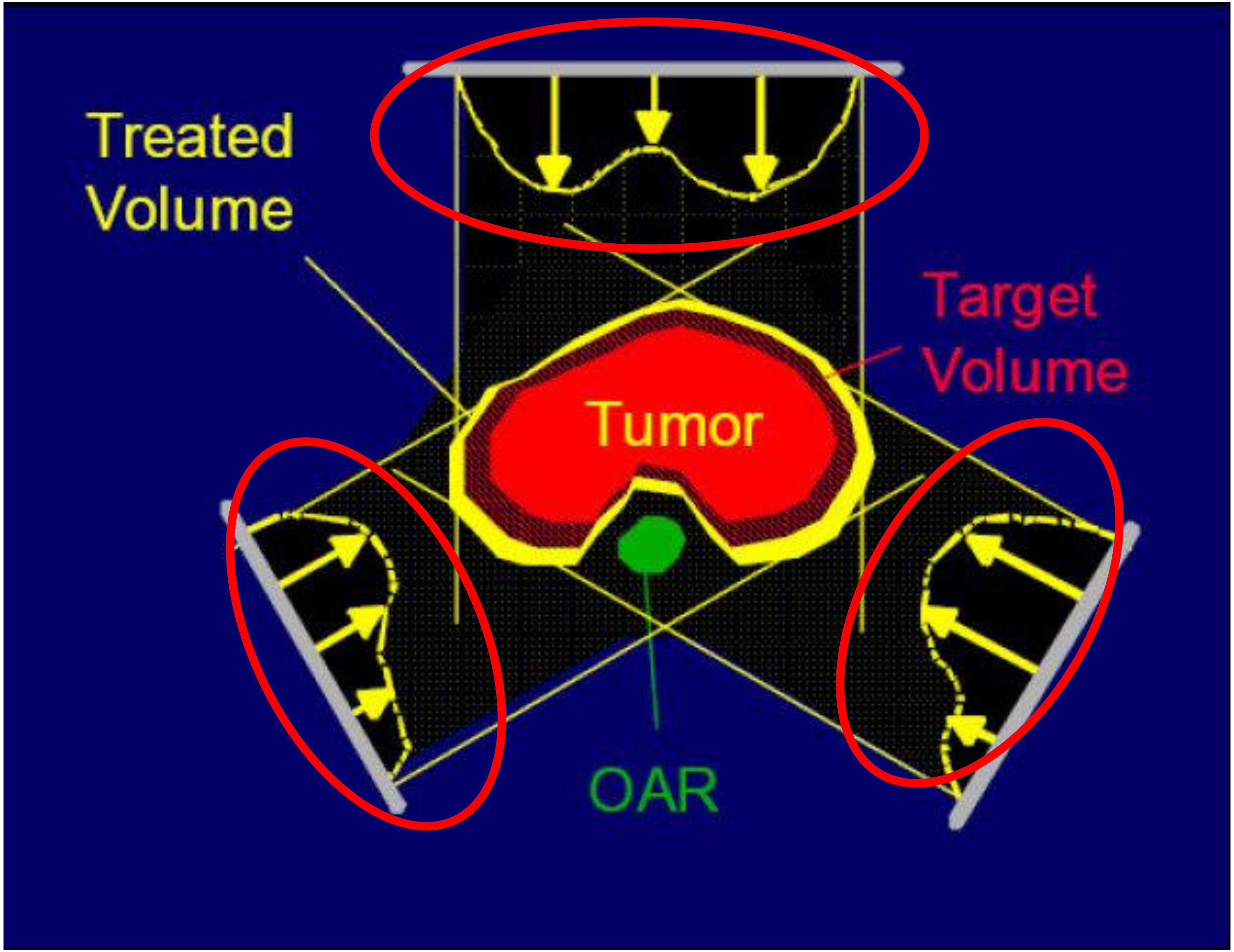
- This process of changing beam intensity profiles to meet the goals of a composite plan is called **intensity modulation**.

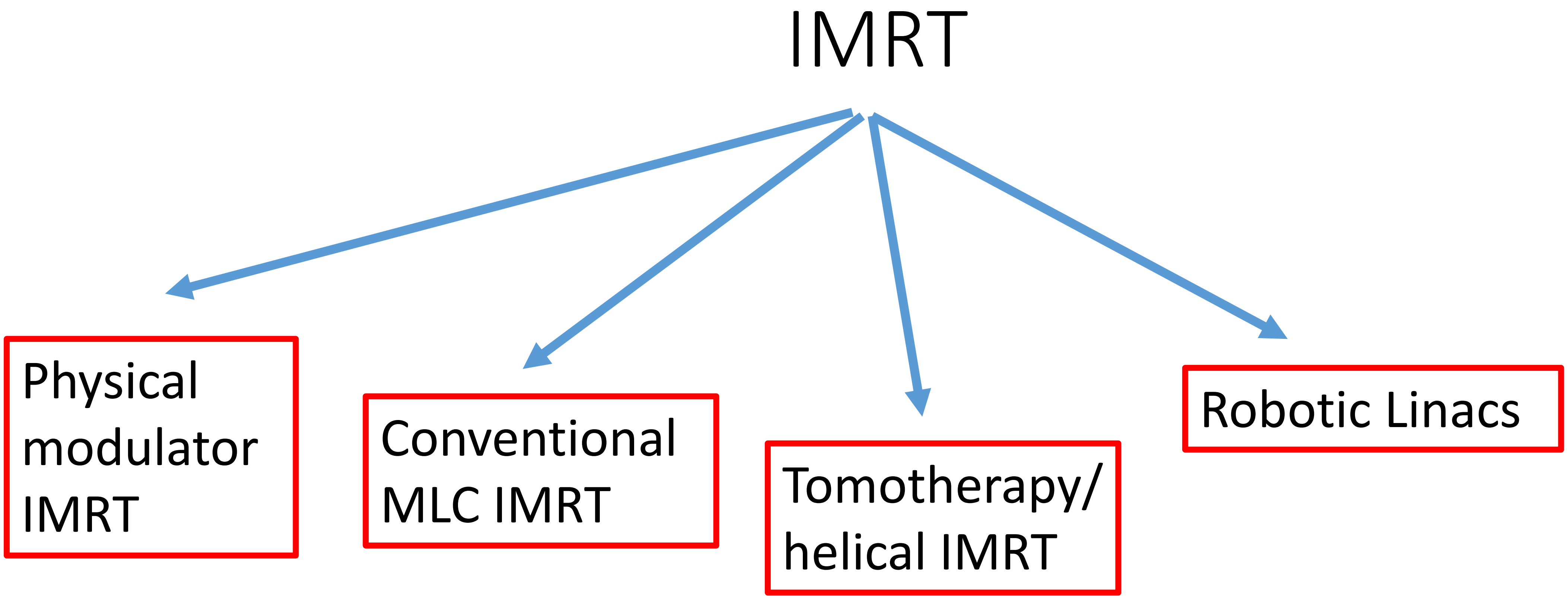
IMRT: Intensity modulation radiation therapy

- In IMRT, a non-uniform fluence is delivered to the patient from any given position of the treatment beam to optimize the composite dose distribution.

- The treatment criteria for plan optimization are specified by the planner and the optimal fluence profiles for a given set of beam directions are determined through “inverse planning”.

- The treatment planning program divides each beam into a large number of beamlets and determines optimum setting of their fluences or weights.


Treated Volume
Target Volume
Tumor
OAR



*ASTRO-AAPM Collaborative working group

Conventional MLC IMRT:
--fixed gantry and rotating beams

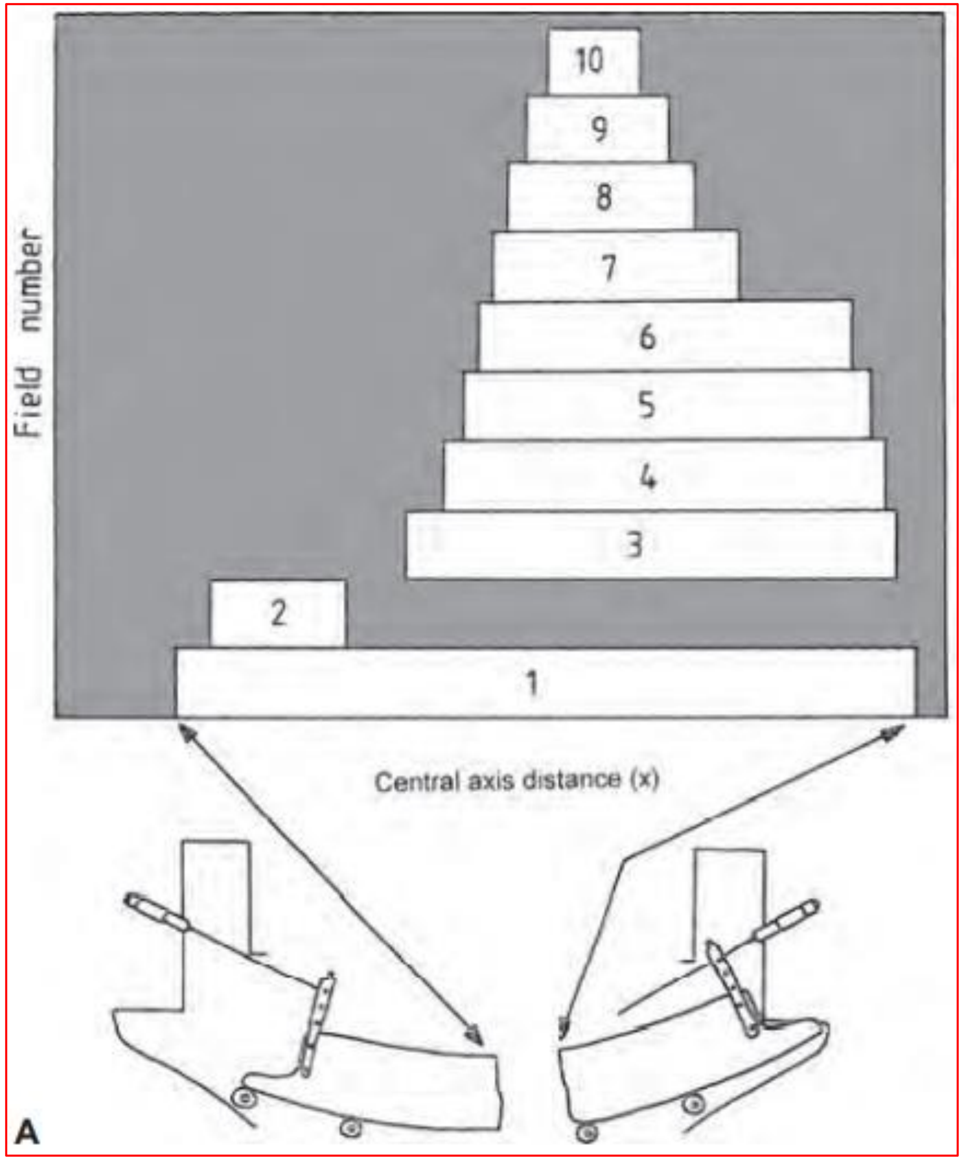
Fixed gantry angle IMRT

✓ Segmental delivery:

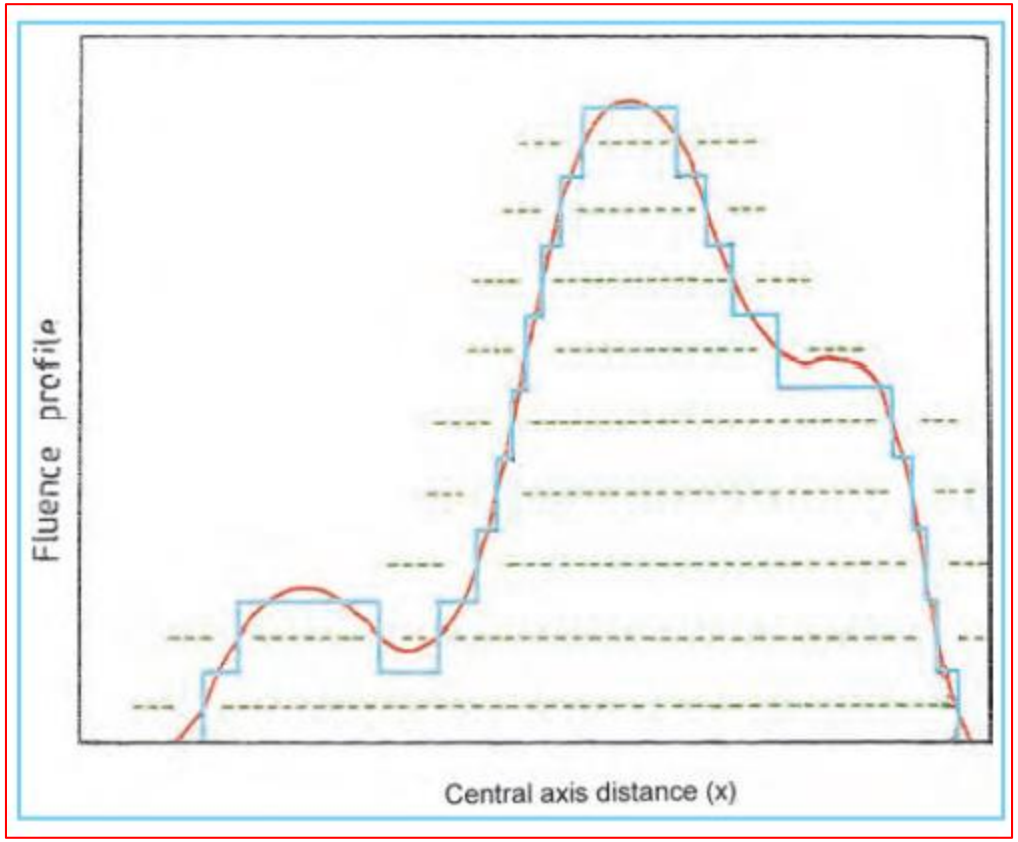
- ❑ stack arrangement of fixed uniform intensity sub fields
- ❑ Accelerator turns off in between
- ❑ **Step and shoot**
- ❑ Leaves may sweep or close-in
- ❑ Easy to operate but On and off accuracy may be an issue

✓ Dynamic MLC delivery

- ❑ leaves sweep simultaneously and unidirectionally, each with a different velocity as a function of time
- ❑ accelerator beam is on while the leaves are moving
- ❑ **Sliding window IMRT**



Field number
10
9
8
7
6
5
4
3
2
1
Central axis distance (x)
A



Fluence profile
Central axis distance (x)

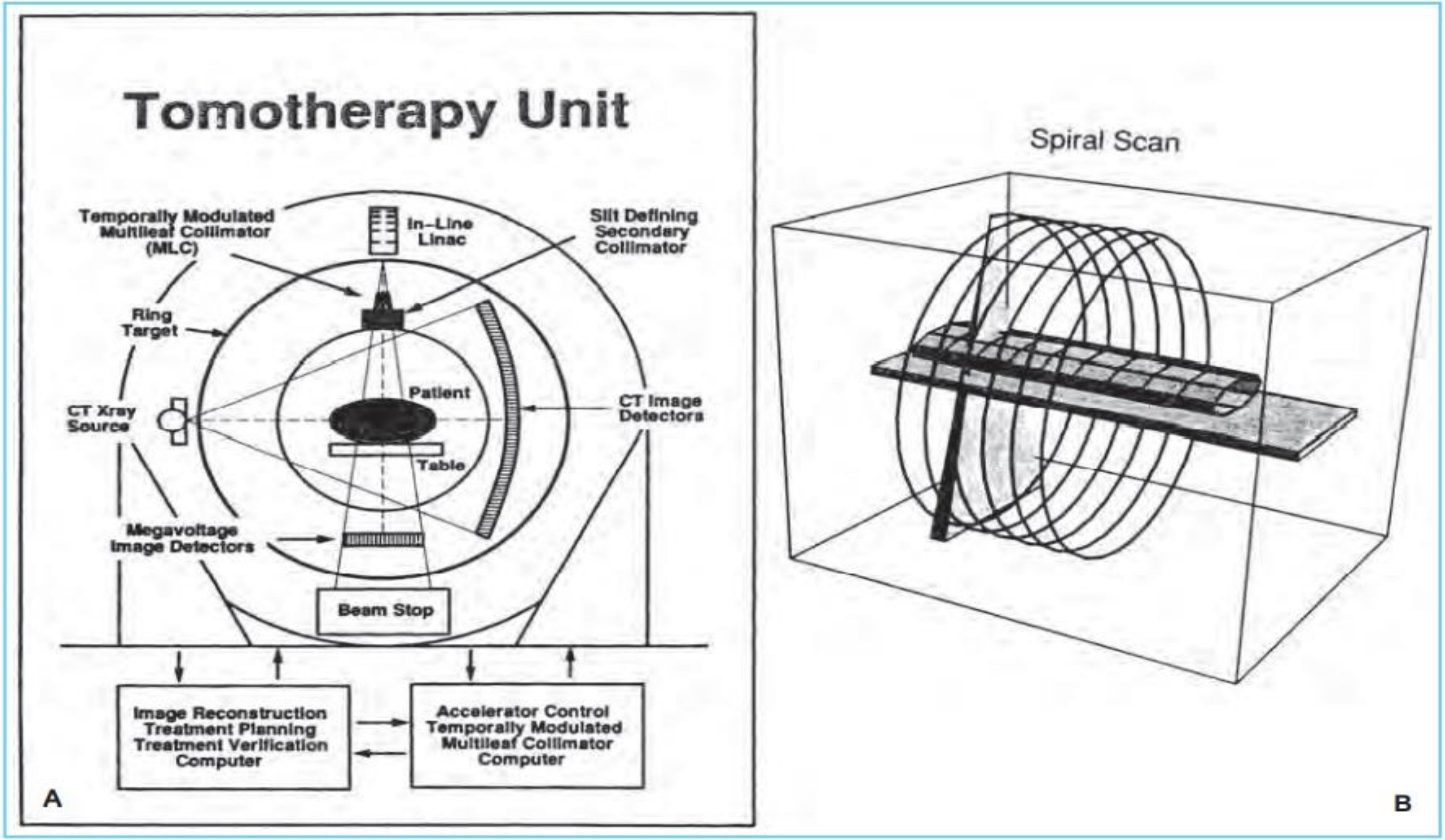
Rotating beams IMRT

- ✓ IMAT

- ✓ VMAT
  - ❑ Gantry moves continuously, while MLC leaves and dose rate changes continuously

Tomotherapy/Helical IMRT

- The patient is treated slice by slice by IMBs in a manner analogous to CT imaging.
- A special collimator is designed to generate the IMBs as the gantry rotates around the longitudinal axis of the patient.



Tomotherapy Unit
Temporally Modulated Multileaf Collimator (MLC)
In-Line Linac
Slit Defining Secondary Collimator
Ring Target
Patient
CT Xray Source
CT Image Detectors
Table
Megavoltage Image Detectors
Beam Stop
Image Reconstruction Treatment Planning Treatment Verification Computer
Accelerator Control Temporally Modulated Multileaf Collimator Computer
A
Spiral Scan
B


TomoTherapy
C

IGRT: Image Guided Radiation Therapy

- Broadly, IGRT may be defined as a radiation therapy procedure that uses image guidance at various stages of its process: patient data acquisition, treatment planning, treatment simulation, patient setup, and target localization before and during treatment.

- In the present context, we will use the term IGRT to signify radiotherapy that uses image guidance procedures for target localization before and during treatment

- A very important requisite given that we have very conformal dose distributions

IGRT

- Eventually most radiotherapy will be IMRT, even many palliative treatments, e.g., re-treatment

- All IMRT should be image-guided: – IMRT spares critical tissues (conformal avoidance), produces higher dose gradients.
  - – IGRT enables higher gradients to be delivered safely and effectively.
  - – IGRT enables a smaller setup margins to be defined.

- In some radiotherapy sites, e.g., prostate, IGRT is more relevant

- Afterall, equating it with surgery as a local therapy, we too need to see it and the treat it!!

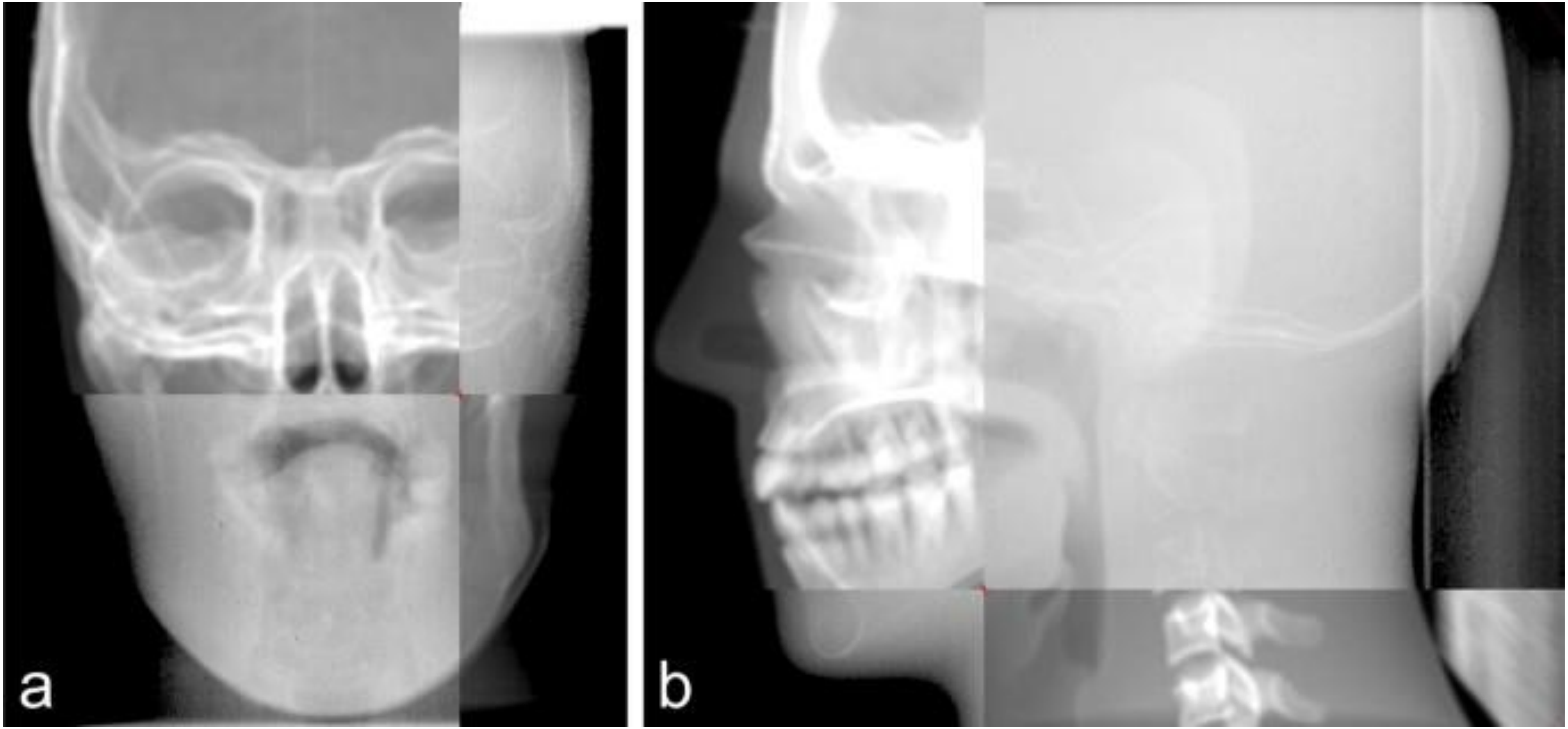
2D systems- x rays

ELECTRONIC PORTAL IMAGING DEVICES

Portal images and radiographic images

MV and KV imaging; KV imaging also enable fluoroscopy and MV enable online monitoring of target position

2D imaging is inadequate to obtain volume information


a
b

CT in Treatment Room

CT in the Treatment Room “First CT then Treat”

Siemens CT vision: Primus Linac+diagnostic CT
“CT on Rails”

GE CT + Varian Linac

Cone Beam Imaging: KV

The on-board kV imaging system is capable of radiography, fluoroscopy, and cone-beam computed tomography

The kVCBCT involves acquiring planar projection images from multiple directions as the gantry is rotated through 180 degrees or more

MV CBCT

- Possible with the existing EPID setting, no extra hardware required
- Less contrast as compared to better contrast with KV CBCT , hence poor soft tissue resolution
- No issues with artifacts: dental fillings, hip implants
- No need to extrapolate attenuation coefficients
- Imaging dose easily quantified as therapeutic beam dose known

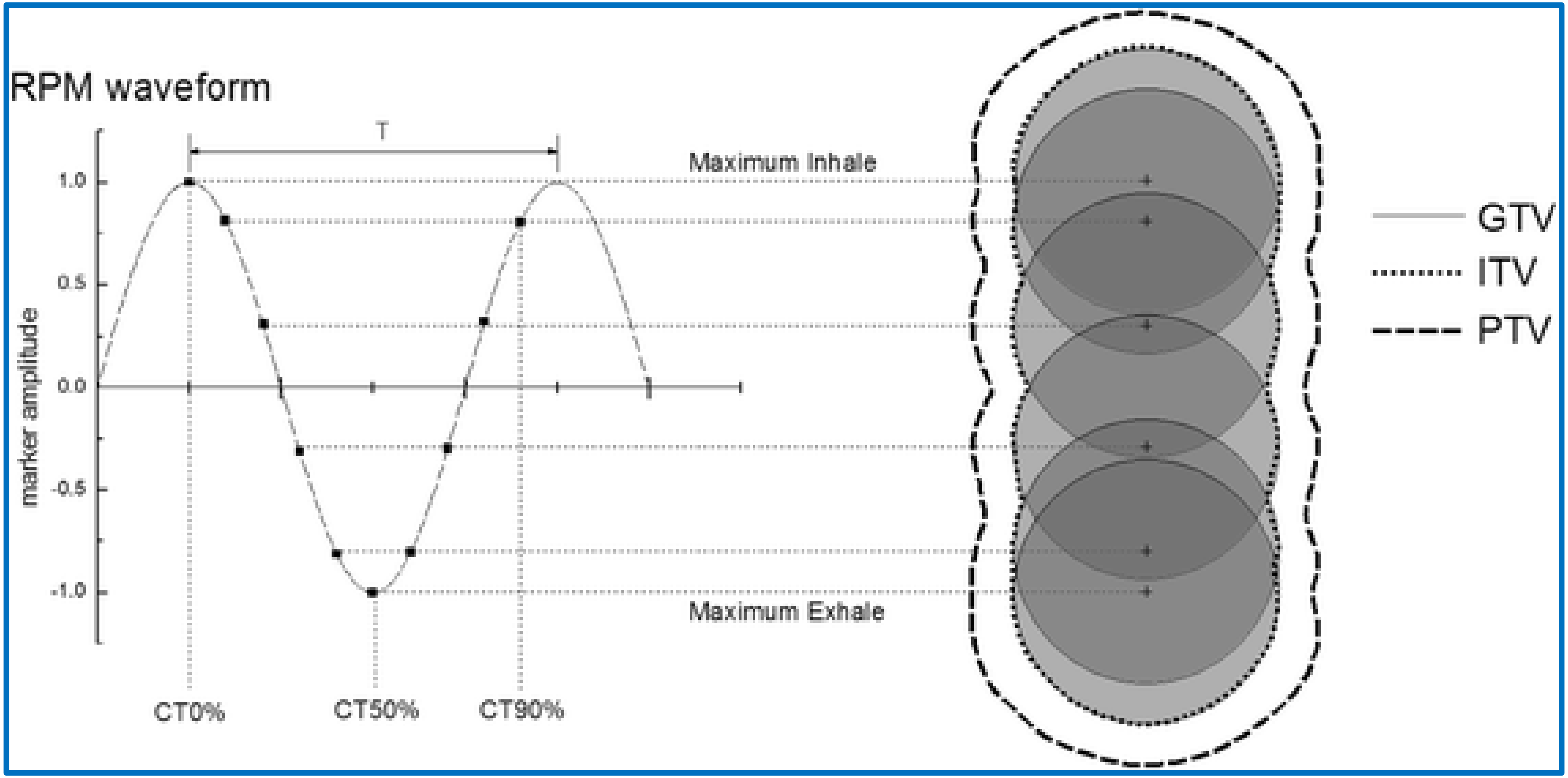
So far so good!

MOTION
MANAGEMENT

- There is internal movement and deformation in multiple organs with respiration
- Tumors in the lung, liver, pancreas, esophagus, breast, kidneys, prostate, and other neighboring sites are known to move due to respiration.
- AAPM TG 76 recommends considering respiratory management techniques if range of motion exceeds 5mm in lung tumours
- Thus, need for intra-fraction motion management techniques arises

Intra- fraction motion management

- 4D- CT
- Real time tumour tracking
- Electromagnetic field tracking, MR tracking



4D respiratory trace

Concept of ITV

Breath- hold treatment

Patients' console respiratory trace image, Yellow colour indicates radiation beam on time

Real time tumour tracking

- It detects the respiratory motion and dynamically reposition the radiation beam in order to follow the tumor's changing position.

- Because of the difficulty of detecting the tumor itself, surrogate markers (external fiducials on the skin surface or internal fiducials implanted directly into the tumor) are used in most cases.

- The time delay between the detection of motion and the corrective action should be short (on the order of 100 milliseconds)

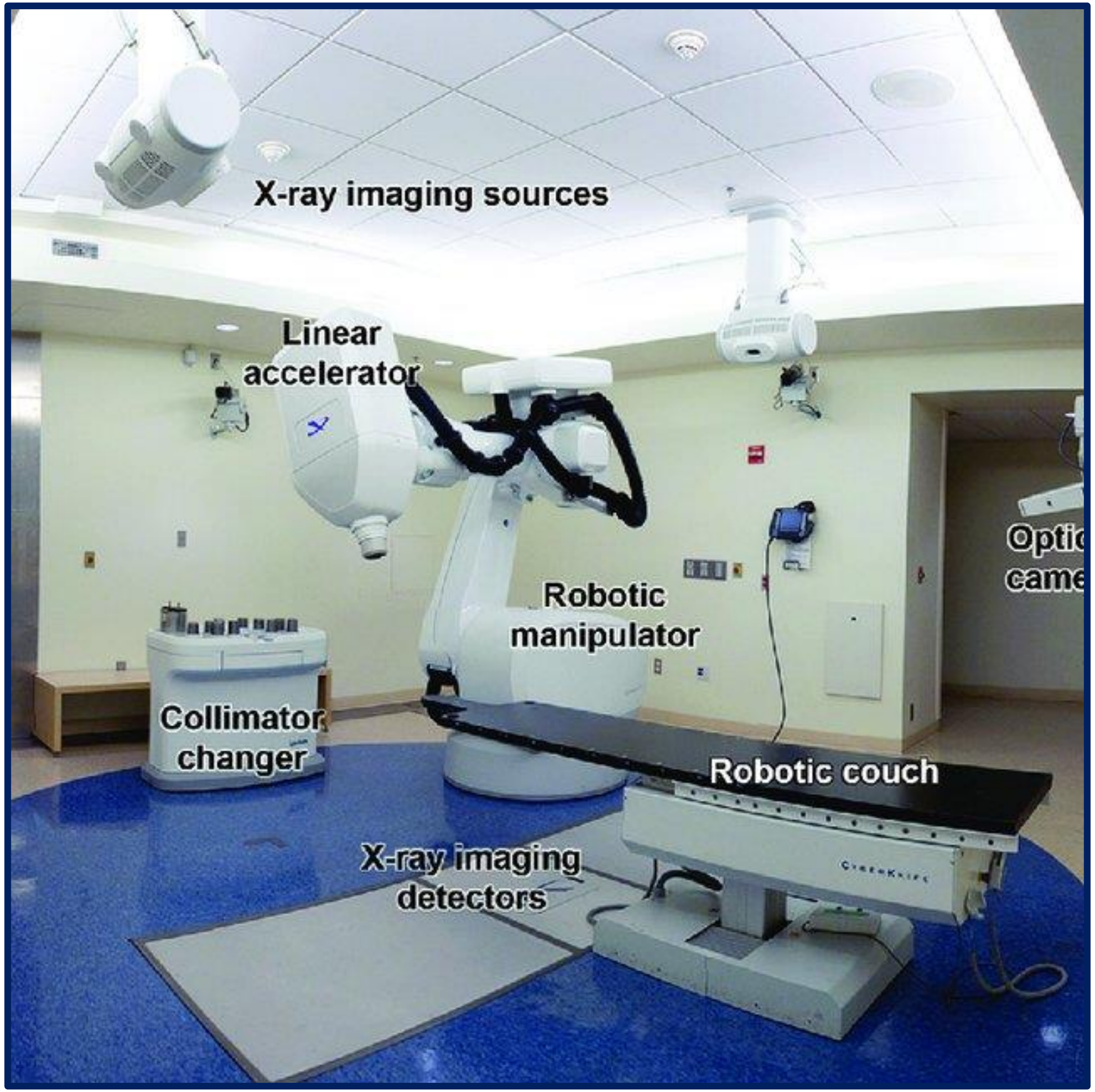
Exactrac/Brainlab system

2 real time imaging systems

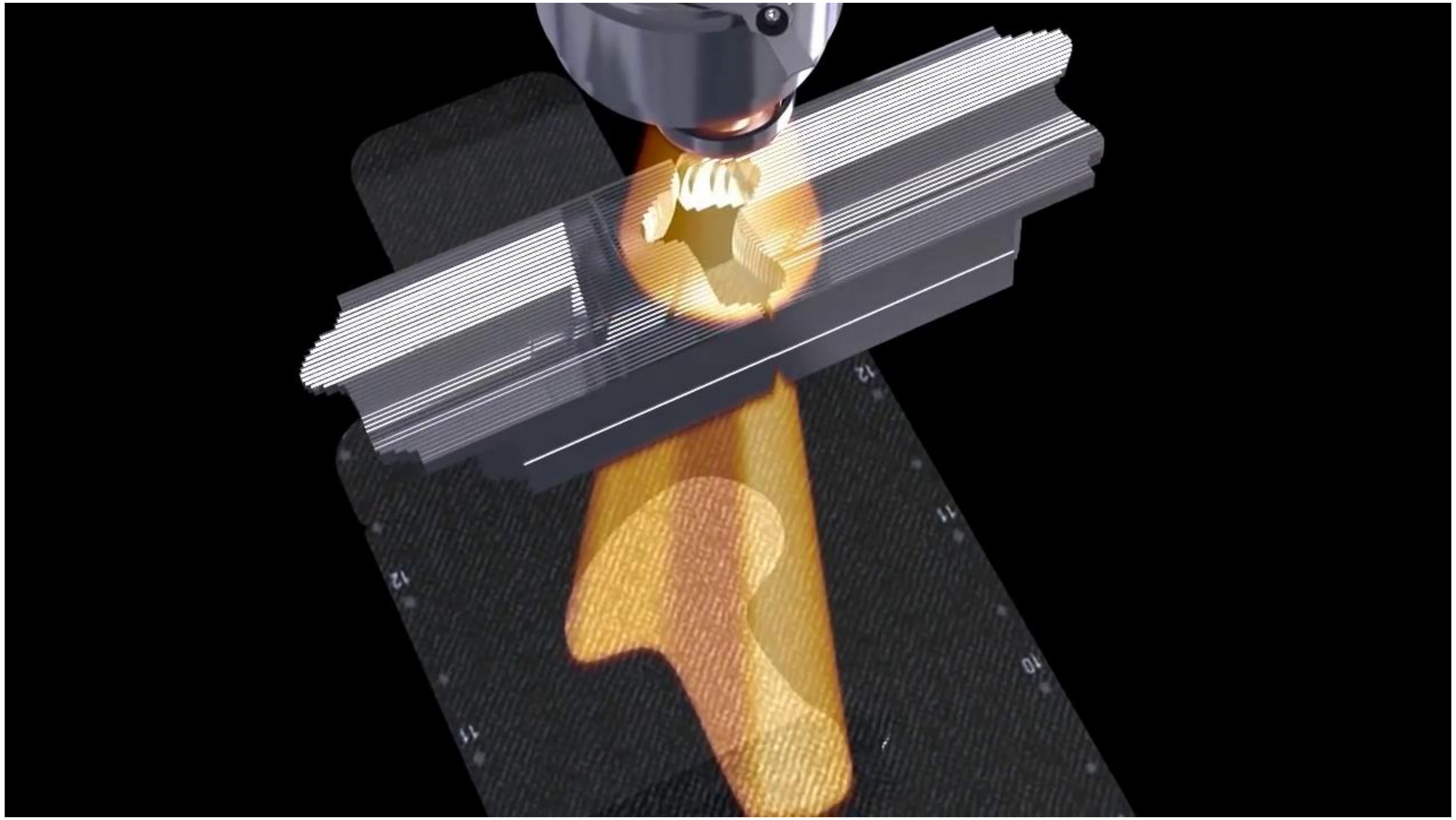
- Optical system with Infra-red cameras
- Fluoroscopic system (x ray tubes in floor and detectors in ceiling)
- 6D couch

Cyberknife


B


X-ray imaging sources
Linear accelerator
Robotic manipulator
Collimator changer
Robotic couch
X-ray imaging detectors

Miscellaneous physics concepts: MLCs



Tertiary collimators: **Multi- leaf collimators**

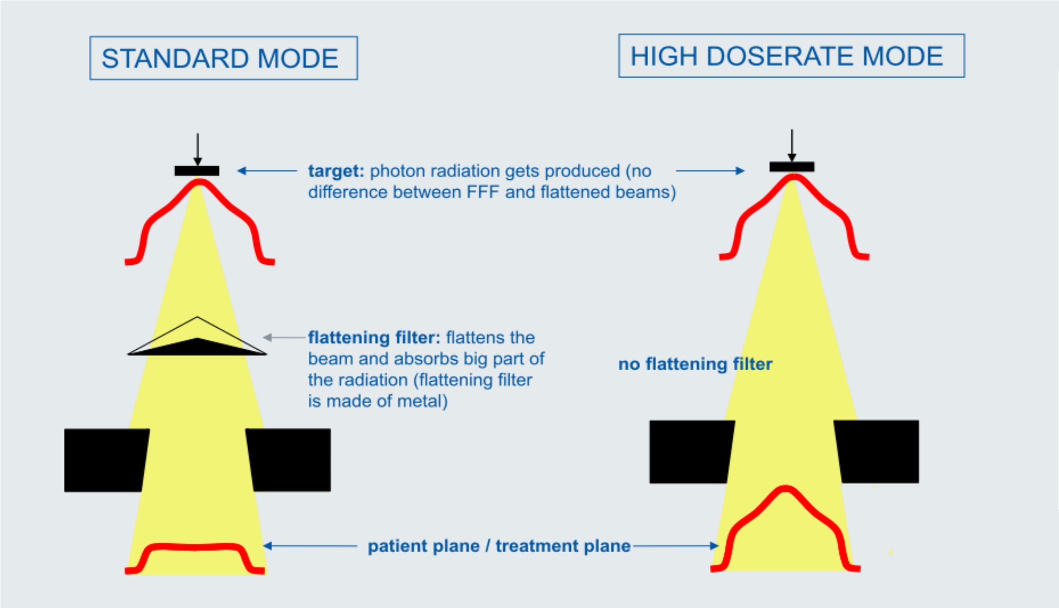
- Leaves that can be driven automatically, independent of each other, to generate a field of any shape

- Typically consists of 60 to 80 pairs, independently driven. The individual leaf has a width of 1 cm or less as projected at the isocenter.

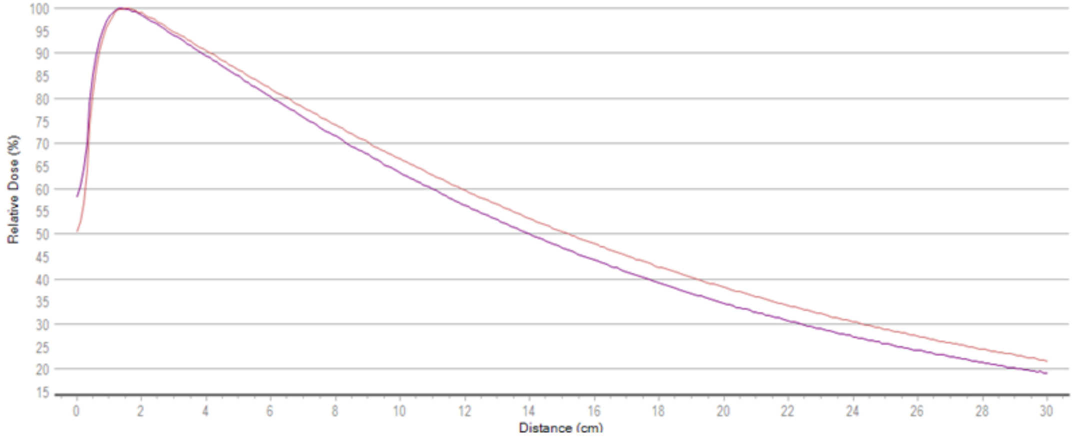
- The leaves are made of tungsten alloy & have thickness along the beam direction ranging from 6- 7.5 cm. The leaf thickness is sufficient to provide primary x-ray transmission through the leaves of less than 2% (compared with about 1% for jaws and 3.5% for Cerrobend blocks). The interleaf (between sides) transmission is usually less than 3%. The primary beam transmission may be further minimized by combining jaws with the MLC in shielding areas outside the MLC field opening

- Imp MLC QA- Stability of leaf speed, Dose profile across adjacent leaves, Leaf acceleration and deceleration, Positional accuracy of leaves, Routine mechanical check, Collimator transmission

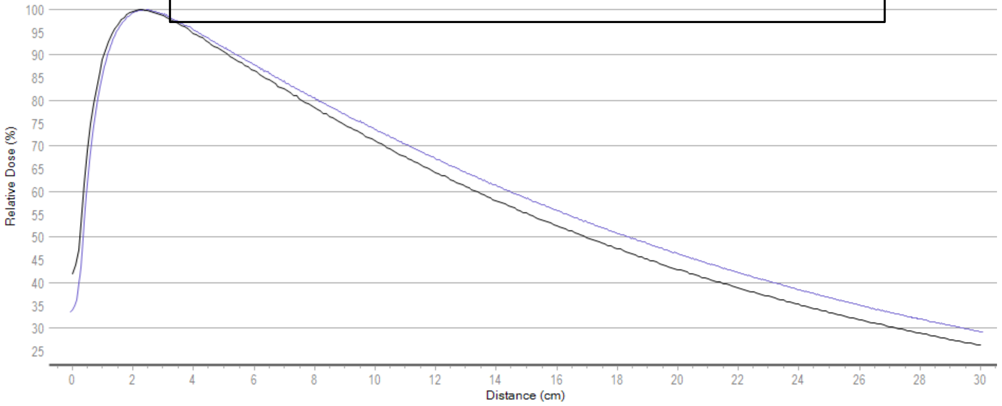
Flattening Filter Free (FFF) beam



PDD 6MV FF & 6MV FFF



PDD 10MV FF & 10MV FFF



Energy	PDD(10 cm)	SURFACE DOSE	Dmax
6MV FF	65.9	51.2	14.9
6MV FFF	63.6	58.99	12.95
10 MV FF	73.8	37.6	24.8
10MV FFF	71.13	43.01	23.0

Rule of thumb:
X6FFF ~ X4, X10FFF ~ X8

Very important!

TABLE 20.1 IMRT Quality Assurance Program[a]

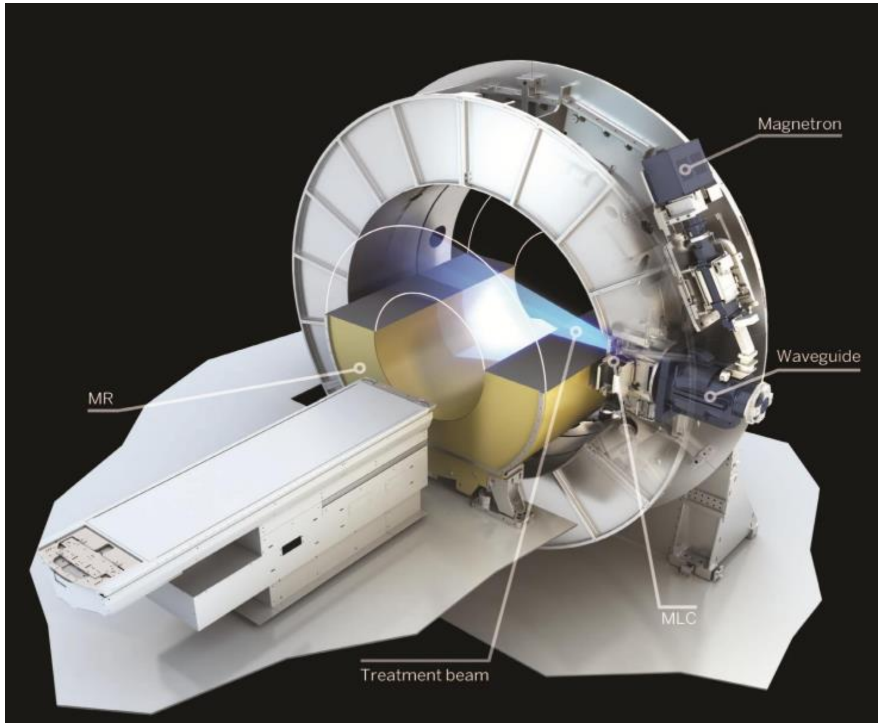
Frequency	Procedure	Tolerance
Before first treatment	Individual field verification, plan verification	3% (point dose), other per clinical significance
Daily	Dose to a test point in each IMRT field	3%
Weekly	Static field vs. sliding window field dose distribution as a function of gantry and collimator angles	3% in dose delivery
Annually	All commissioning procedures: stability of leaf speed, leaf acceleration and deceleration, multileaf collimator transmission, leaf positional accuracy, static field vs. sliding window field as a function of gantry and collimator angles, standard plan verification	3% in dose delivery, other per clinical significance

Be cautious!

More conformality we achieve, more confident we need to be of our

- Planning CT, Target delineation
- Motion management
- PTV and penumbra margins

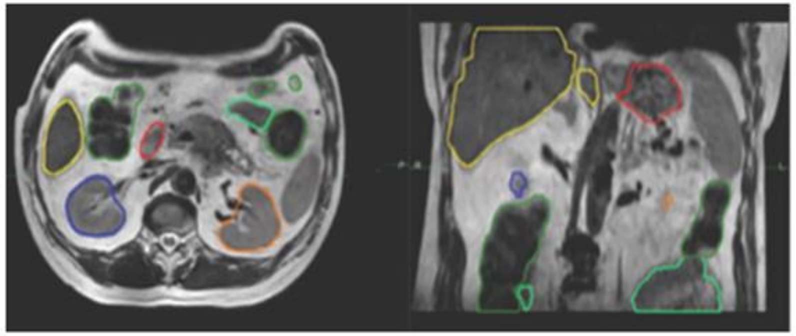
MR-guided system



An overview of the MR-Guided system showing some of the major subcomponents.

- Incorporating MR for simulation & treatment planning allows reproducible millimeter accuracy in soft tissue definition
- Functional imaging (DCE/DWI) allows dose painting to high risk tumor volume for greater tumor control
- MR OBI (on board imaging) allows target and critical structure localization & tracking based on gold-standard anatomy rather than fiducial markers, bony anatomy or other surrogate as in CT
- Intra-fraction anatomic and functional imaging allows early evaluation of tumor response and adaptive treatment escalation or de-escalation to improve tumor control or treatment toxicity

MRI-guided Radiotherapy: An Emerging Paradigm in Adaptive Radiation Oncology



Axial and coronal MRI scans show the interfraction motion of organs at risk (liver, bowel, kidney, stomach, and duodenum) in a patient with pancreas cancer undergoing stereotactic body radiation treatment on the 1.5-T MRI-guided linear accelerator.

- Online MRI-guided RT offers unprecedented opportunities for interfraction and real-time intrafraction adaptation to organ motion and calculation of dose accumulation.

- Using MRI in RT will improve the monitoring of tumor biology during radiation treatment and develop novel imaging biomarkers for assessing tumor response.

- Challenges to MRI-guided RT include real-time volumetric anatomic imaging, reproducible quantitative imaging across different MRI systems, and biologic validation of quantitative imaging.

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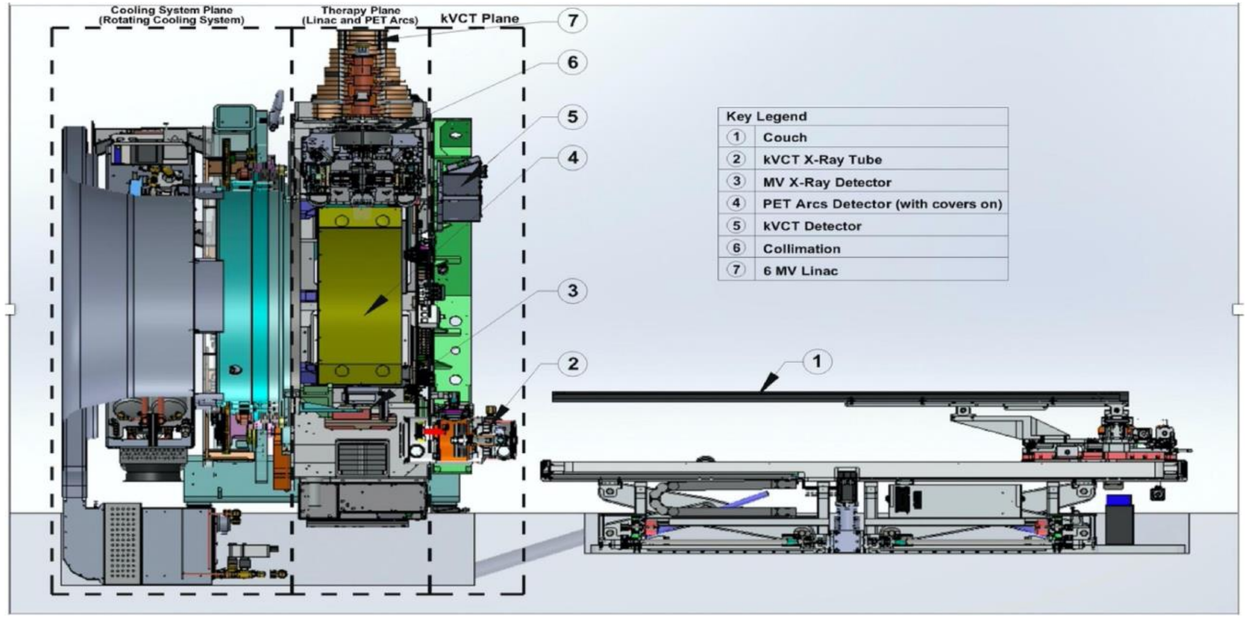
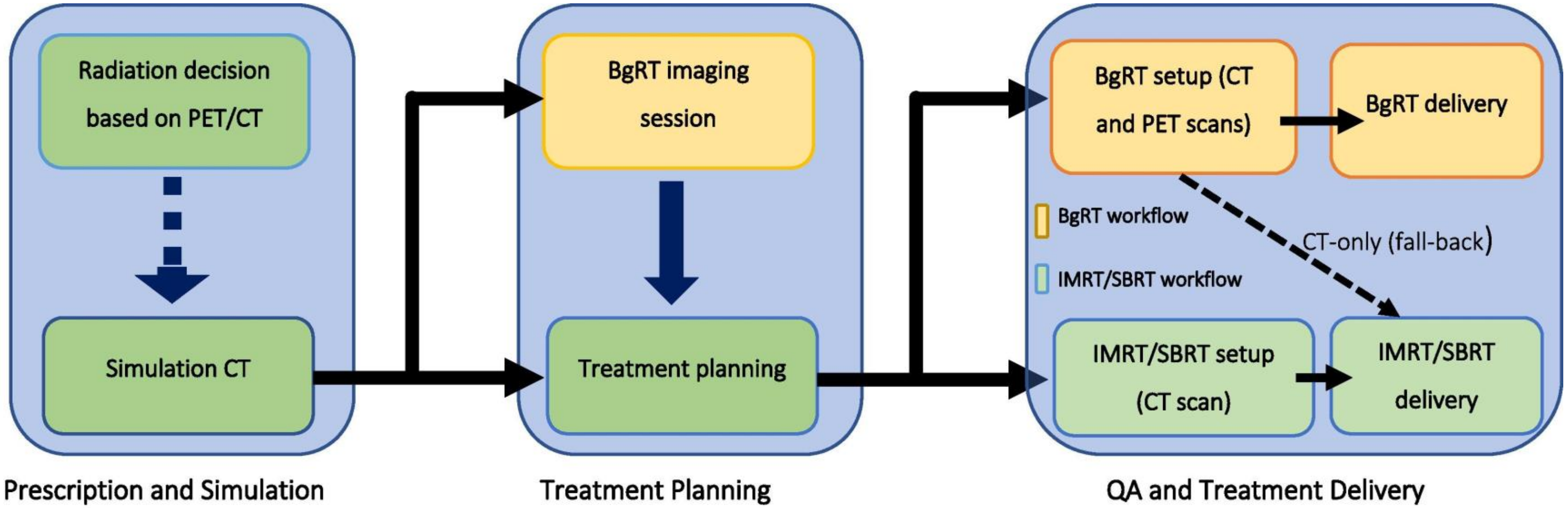
Radiology

PET/CT linac for biology-guided radiotherapy



- BgRT delivery uses annihilation photons emanating from the PET-avid tumor to guide the delivery of beamlets in real-time.
- BgRT treatment technique opens the avenue to debulking advanced and metastatic disease.

An overview of the BgRT system showing some of the major subcomponents.



Clinical workflow of BgRT system.

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