OVERVIEW OF IMAGE GUIDANCE TECHNIQUES IN SRS & SBRT

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WHAT IS IMAGE GUIDANCE?

IGRT, or image guided radiation therapy, is **a technique in which frequent imaging**

– Intrafractional/ Interfraction, is used to enhance accuracy throughout the course of a patient's radiation treatment.*

<u>Requirements-</u>

An image acquisition system.

A set of reference images for comparison.

A software for the comparison match between reference images and CT/MR/PET/USG planning images.

*Diagnostic Imaging a pre-requisite for Radiation Planning

Image Guidance in SRS/SBRT

- Image Guidance involves the use of imaging technology to localize the intended target volume immediately **prior & during** the administration of radiation therapy.

- With the advent of SRS/SBRT the dose is confined to the target volume and conformal avoidance of critical structure

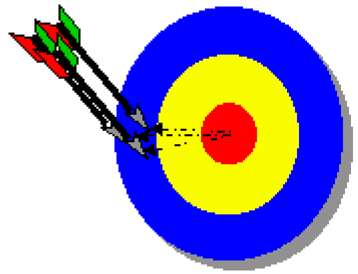
- Due to complexity in treatment delivery, accurate knowledge of patient anatomy during radiation process is of utmost importance

- Internal anatomy is not always well correlated with the surface anatomy

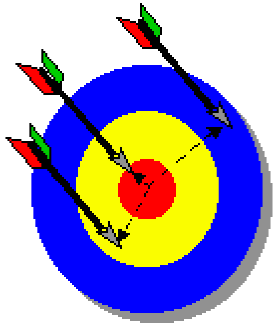
- SRS or SBRT are useless without image guidance
- Goal of IGRT is to manage Intra - fraction motion to reduce margins and optimize treatment
- IGRT allows the assessment of geometric accuracy of patient position prior/during treatment delivery

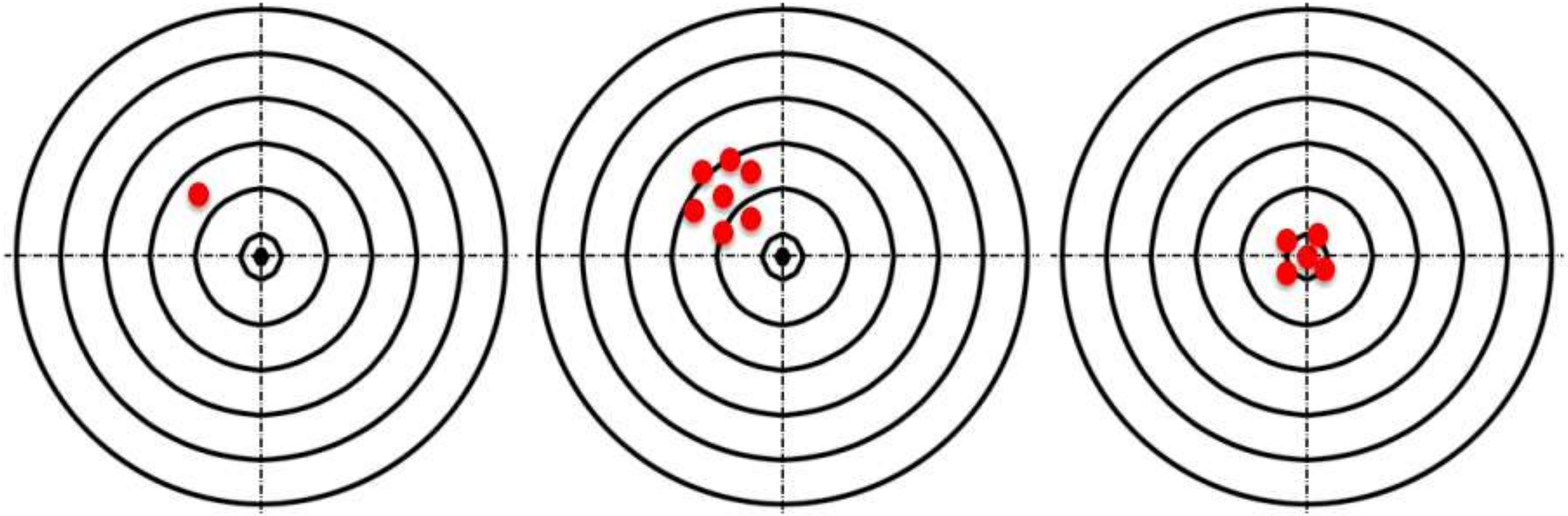
- IGRT mitigate both the systematic and random errors in Radiotherapy
- Systematic error **is a deviation that occurs in the same direction and is of similar magnitude for each fraction throughout the treatment course. Systematic errors are poor accuracy, definite cause and reproducible.**
- Random error **is a deviation that can vary in direction and magnitude during the treatment. Random errors are poor precision, non- specific causes and not reproducible.**

Systematic Error



Random Error





Systematic Error:

- Inaccurate
- Reproducible
- Definite cause

Random Error:

- Imprecise
- Singular

What we want:

- Accuracy
- Precision

WHY IMAGE GUIDANCE FOR SRS/SBRT ?

SRS and SBRT

1.Relatively small tumor targets are treated to high, ablative doses with minimal treatment margins.

2.The target may be relatively fixed or moving and changing shape with respect to body or surrounding structures.

3.Geometric accuracy, in planning and treatment, is of the highest importance, to avoid geographic miss of the tumor or overdosing of adjacent normal tissues.

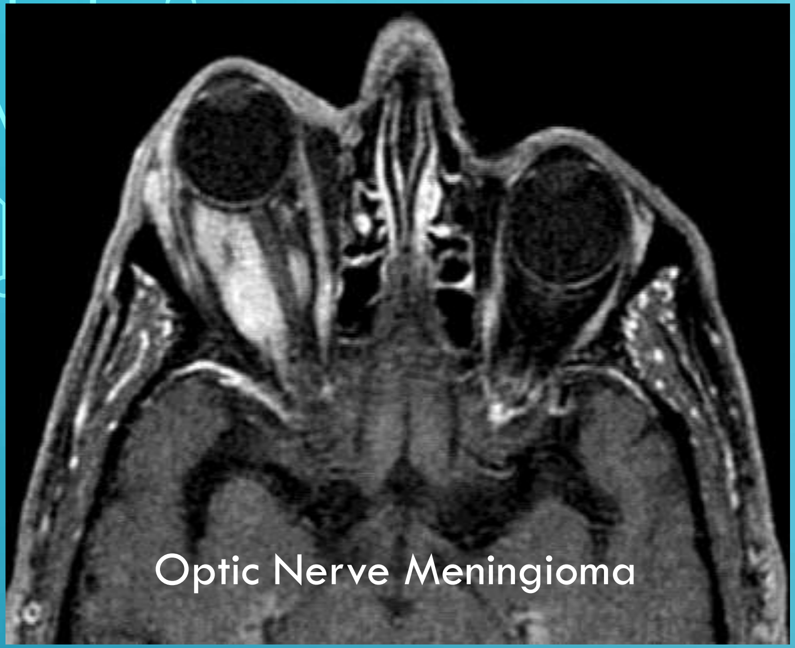
4.Imaging studies of the patient must be of high quality and high resolution for this reason.

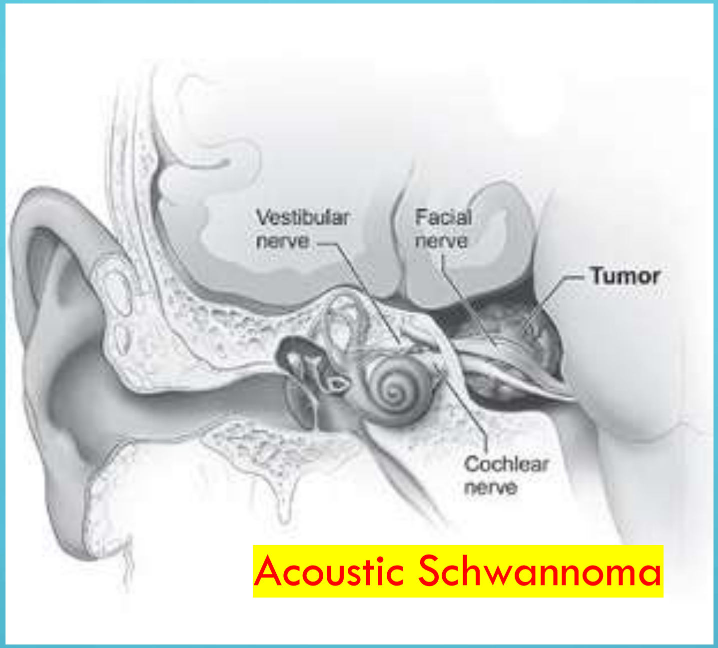
- **the emphasis on reduction on volume exposed to high radio- therapy doses, improving treatment precision as well as reducing radiation-related normal tissue toxicity has increased, and thus there is greater importance given to accurate position verification and correction before delivering radiotherapy.**

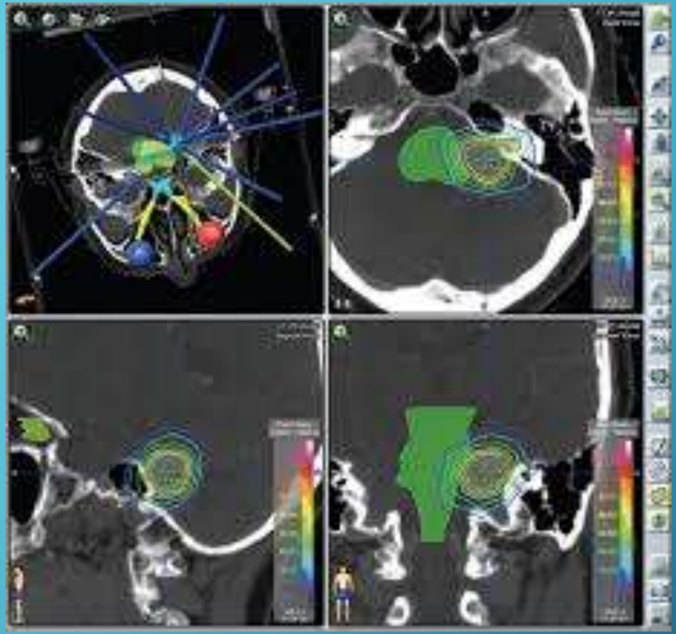
- **delivering "high precision radiotherapy" without periodic image guidance would do more harm than treating large volumes to compensate for setup errors.**

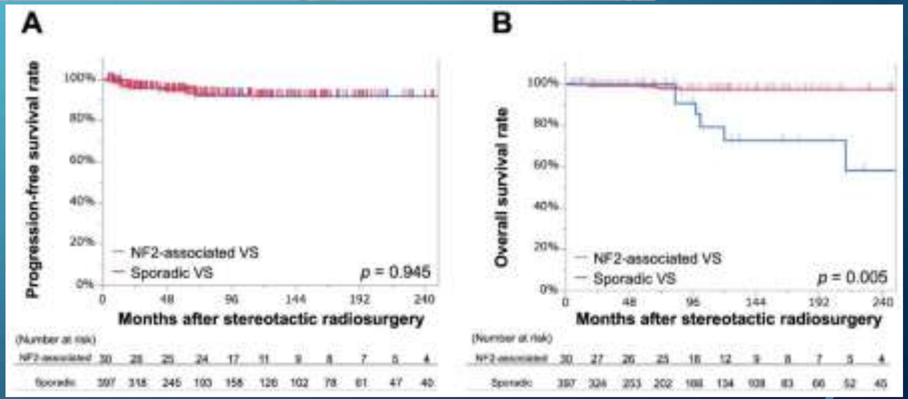
Image Guidance in Radiation Therapy Techniques & applications. Shikha Goyal et al, Radiology Research & Practice, 2014

Control Rates with SRS >90%









Shinaya et al,*Cancers* **2019**, *11*(10), 1498; https://doi.org/10.3390/cancers11101498

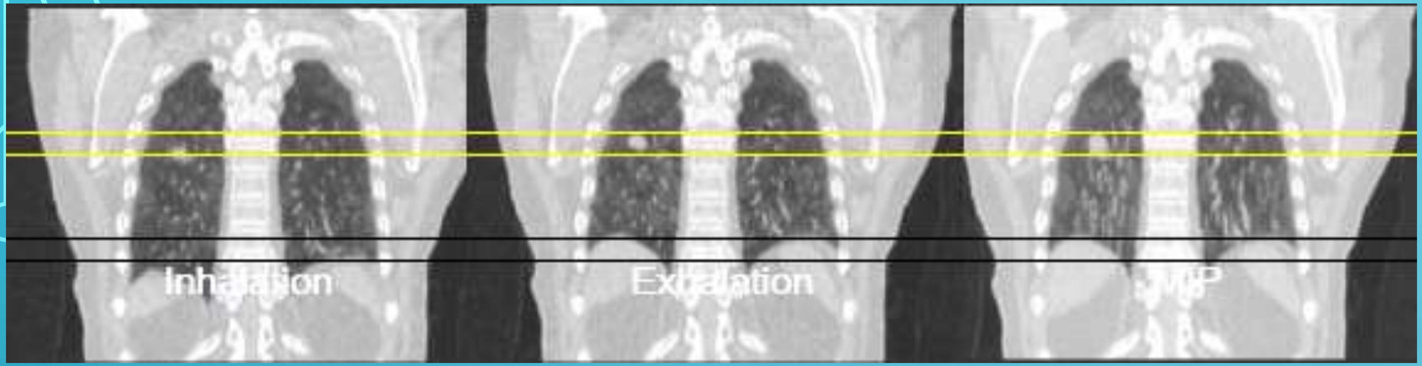
- Surgical Complications-

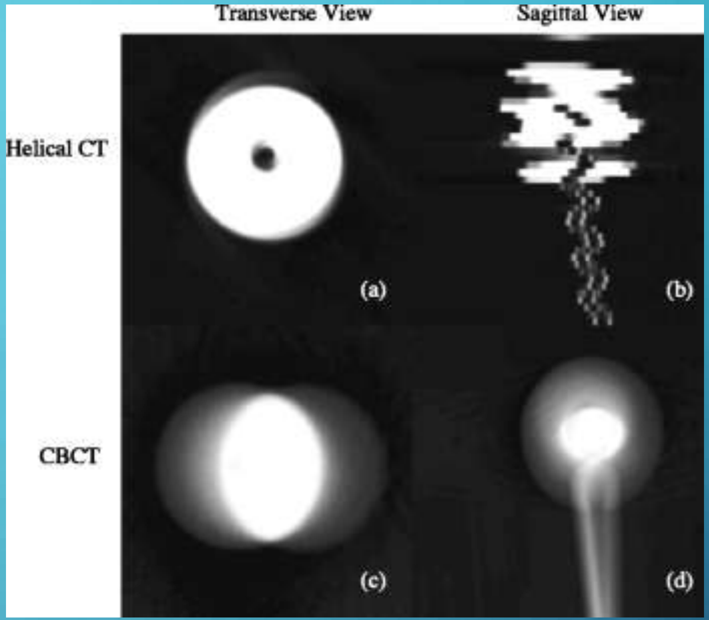
- Permanent vision loss.
- Proptosis.
- Intracranial injury after surgery.
- Cerebrospinal fluid leakage.
- Extension of the tumor into chiasm.

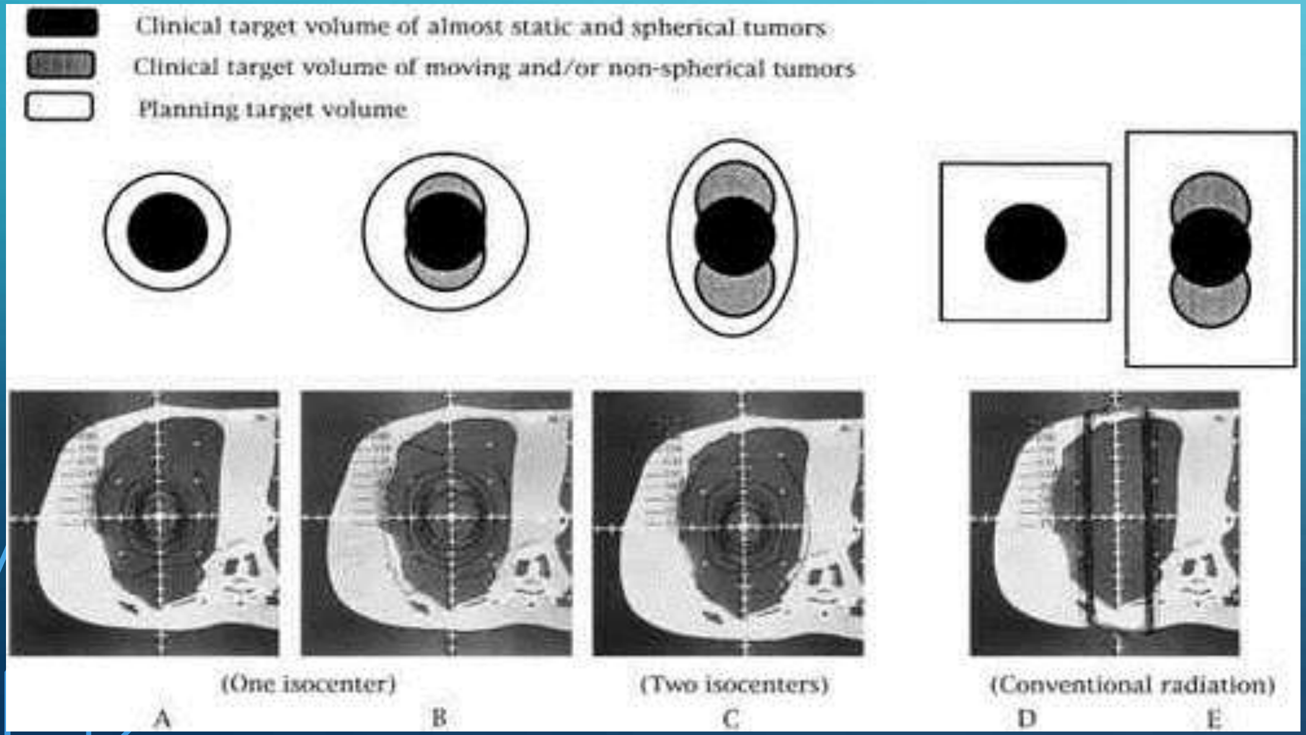
- Surgical Complications
- Hearing loss Tumor growing back.
- Tinnitus (ringing in the ear).
- Cerebrospinal fluid (CSF) leaks.
- Infection of the incision or meningitis.
- Dizziness, balance problems,
- headaches.

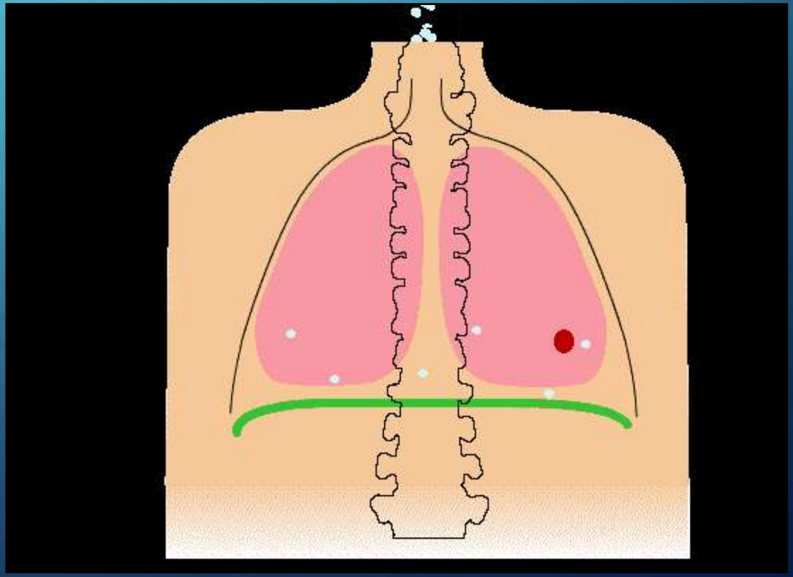
SBRT LUNG – A CHALLENGE

- Mobile target









✓**High precision:**
High degree of reproducible spatial correlation of target and the radiation source.

✓**High Accuracy(<1mm)**
Delivering intended dose within 1 mm of planned position

✓**Rapid fall of radiation dose at periphery of the target:**
Minimizes dose to normal tissue.

✓**High dose conformity**

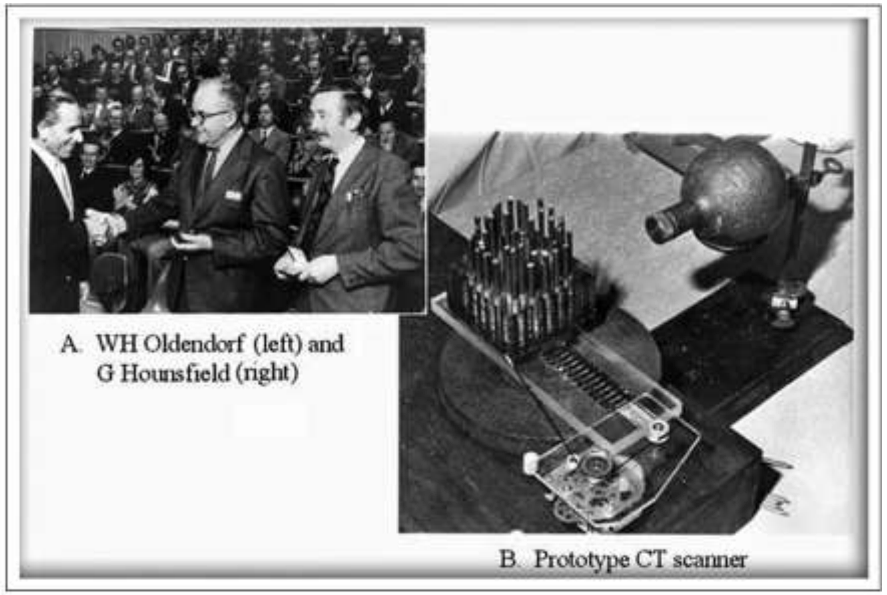
- When you create an SRS Plan and wish to confirm the spatial localization of lesion at the delivery unit

- When you have a moving target & create an SBRT plan that needs to confirm the spatial localization of lesion at the delivery unit

Stereotaxic Vs Conventional

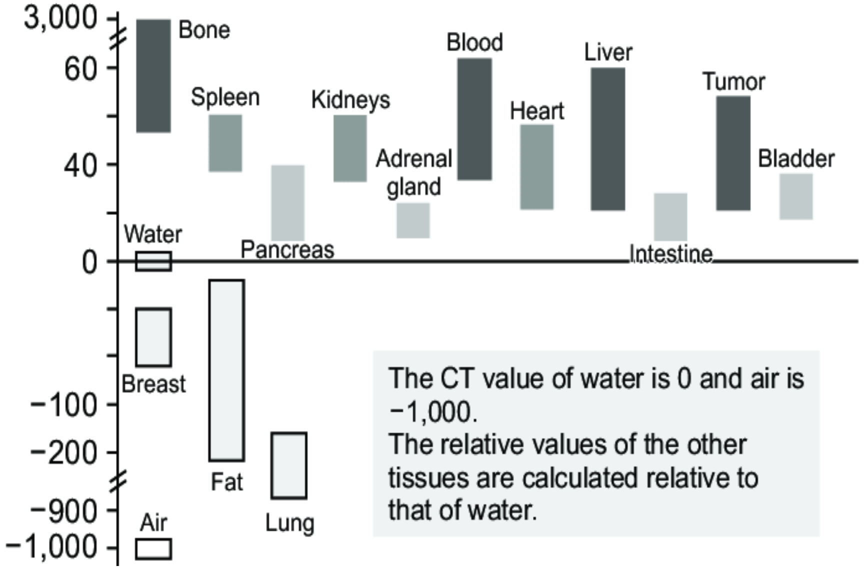
Conventional	Stereotaxic
Coplanar setup	Non- coplanar setup
Large volume	Smaller volume
Limited no.fields (VMAT)	Multiple beams/Arcs
Positional Accuracy 3-5mm	Positional Accuracy 1mm or <1mm
Low Dose 1.8-2 Gy per fraction Or 2.2-2.5 Gy moderate Hypofraction	High Dose 6-25Gy per fraction
25-30 fractions	1-5 fractions

Image Guided Stereotactic Localization



A. WH Oldendorf (left) and G Hounsfield (right)

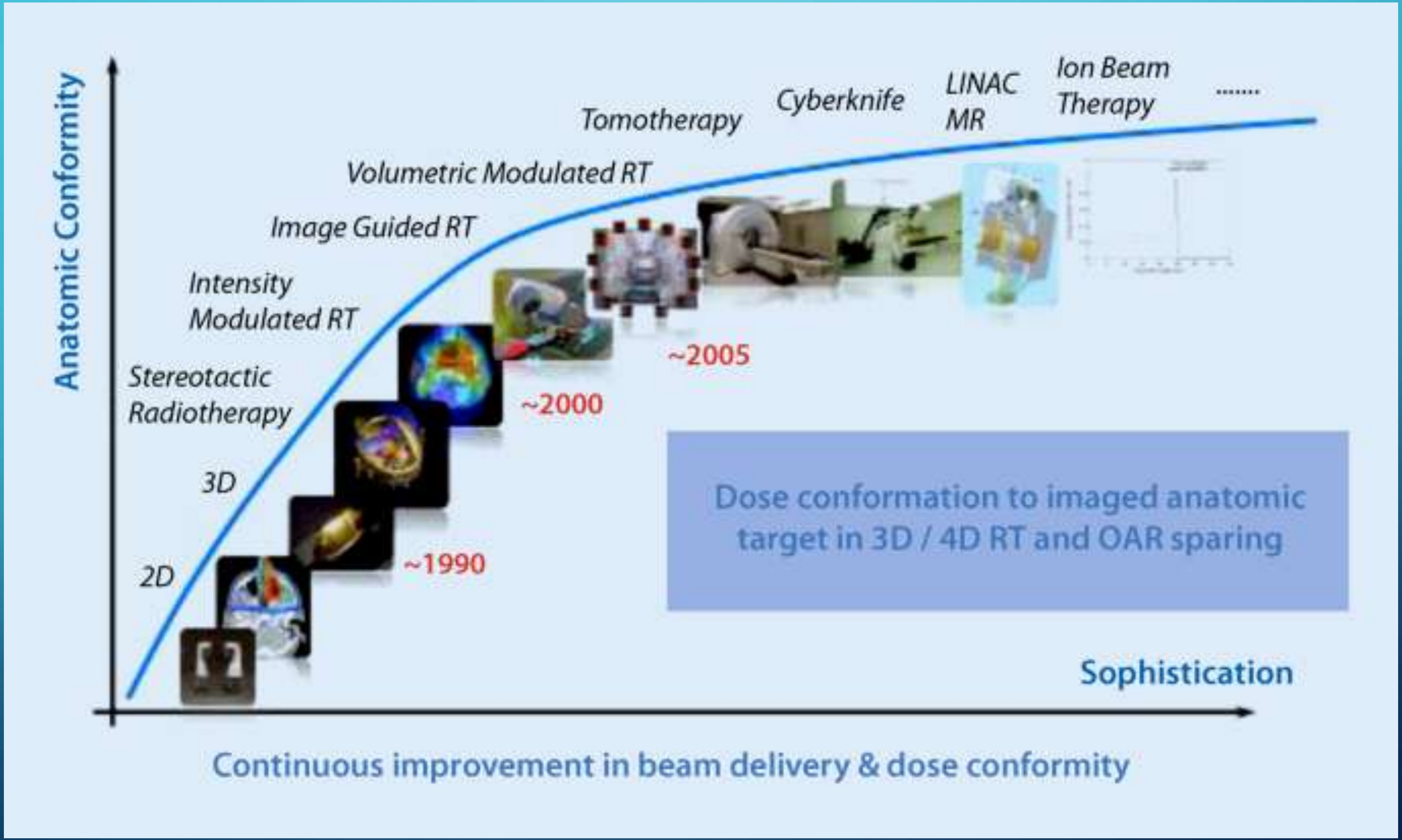
B. Prototype CT scanner



<u>1906-William Oldendorf</u> –Tomographic technique by rotating a radiation source around an axis in a constant linear manner, to differentiate tissue density.

<u>1963-Cormack,</u> used Fourier transformation & back-projection to reconstruct the cross-section of radiographic images

<u>1967-Godfrey Hounsfield</u> gave a computed solution to reconstruction of images based on photon transmission, when X-Rays are taken in all directions around an object translating along an axis



Anatomic Conformity
Ion Beam Therapy
LINAC MR
Cyberknife
Tomotherapy
Volumetric Modulated RT
Image Guided RT
Intensity Modulated RT
Stereotactic Radiotherapy
3D
2D
~1990
~2000
~2005
Dose conformation to imaged anatomic target in 3D / 4D RT and OAR sparing
Sophistication
Continuous improvement in beam delivery & dose conformity

Image Guidance

- IGRT is any imaging at the pretreatment and treatment delivery stage leading to an action that can improve or verify the accuracy of radiotherapy delivery
- Verification-Comparing images (or data) of the treatment delivered with that planned. Information from 2D, 3D or 4D systems to give different translational and rotational set-up data.
- Reference image- shows the planned geometry of the treatment field

placement relative to internal anatomy or anatomical surrogate such as bone or markers representative of the target. This is used as the standard against which treatment images are assessed.

- <u>Online treatment verification</u>
- This compares the reference images with images taken in the treatment delivery room, immediately prior to the treatment being delivered. Any necessary corrections are applied before the treatment is delivered.

- Ideally, the time taken between online verification and treatment delivery should be as short as possible (a few minutes) to reduce the variation that may occur from patient movement during this time.

- Beyond this timescale, the information may no longer represent the patient's true position during the therapy and repeat imaging may be necessary

Delivery Imaging Verification-Linac-Frameless SRS/SBRT with Hexapod Couch

- CBCT 1- Initial evaluation of Translational and Rotational shifts
- CBCT 2- Verification of applied shifts
- CBCT 3- First Half of Tx
- CBCT 4- Second Half of Tx

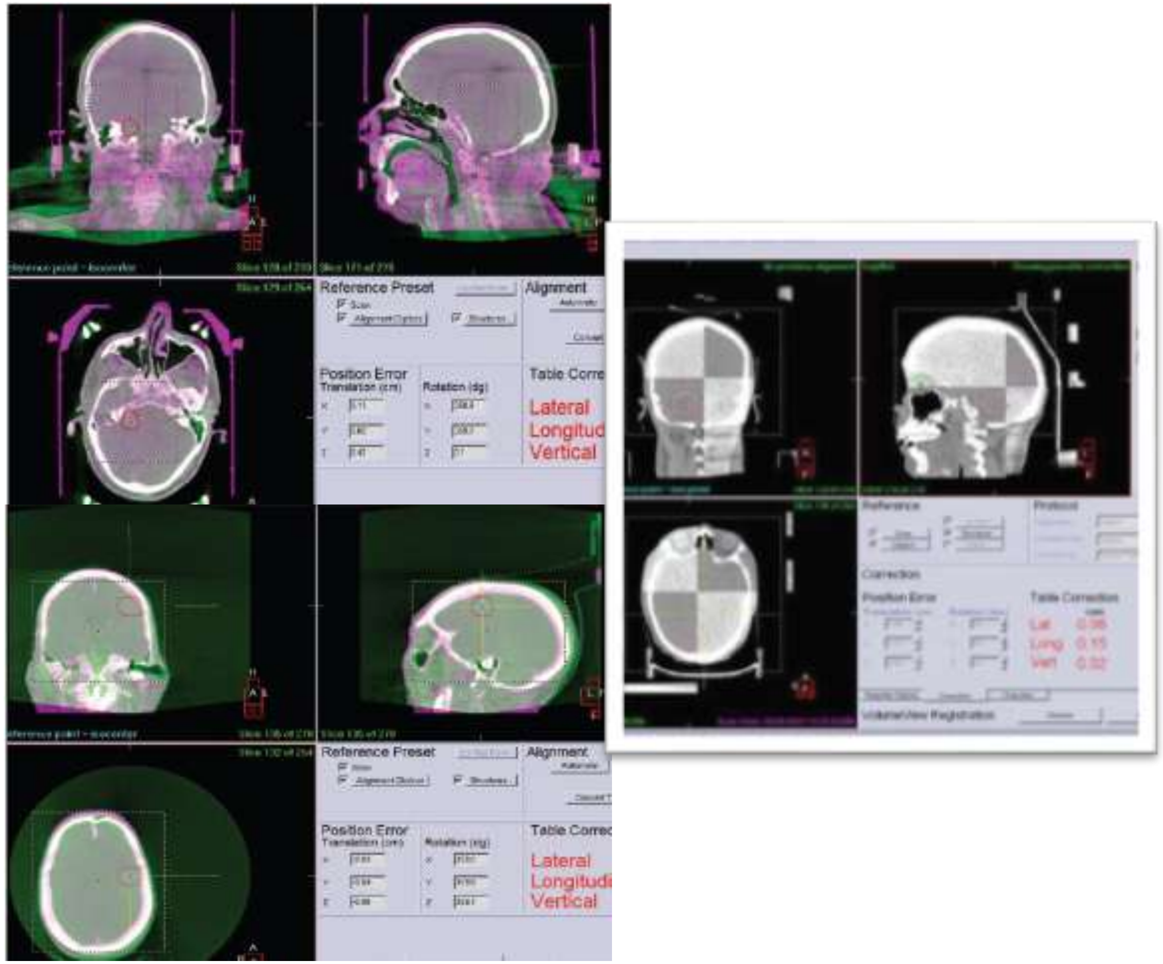
Table 4: Comparison of parameters with frame and without frame before correction

Parameters	Mean	SD	Mean	SD	*T* value	*P* value
X mm	1.00	0.30	-0.41	0.09	1.08	0.2801
Y mm	0.20	1.20	1.10	1.10	1.31	0.1902
Z mm	–0.10	0.31	–0.50	1.30	0.73	0.4654
Roll (θ°)	0.32	0.70	-0.11	0.78	1.10	0.2713
Pitch (θ°)	–0.44	0.66	0.20	0.44	0.45	0.6527
Yaw (θ°)	0.20	0.40	0.29	0.35	0.06	0.9522

Table 5: Comparison of parameters with frame and without frame after correction

Parameters	Mean	SD	Mean	SD	*T* value	*P* value
X mm	0.60	1.80	0.11	0.20	0.42	0.6745
Y mm	0.20	0.60	0.20	0.40	0.00	1.0000
Z mm	0.00	0.50	0.20	0.20	0.87	0.3843
Roll (θ°)	0.01	0.27	0.09	0.23	0.23	0.8181
Pitch (θ°)	0.06	0.15	0.00	0.12	0.00	0.8181
Yaw (θ°)	0.01	0.09	0.00	0.09	0.96	0.3371

*P=<0.05 is significant



Kataria T, et al. Frame-based radiosurgery: Is it relevant in the era of IGRT? Neurol India 2013;61:277-81.

Intrafractional verification

Evaluates the set-up and motion during a single treatment fraction delivery.

The effect of intrafractional movement can be accounted for in treatment margins and, if significant, can be reduced using the following methods:

- ❖ Terminating the treatment beam if movement occurs outside predefined tolerances
- ❖ Timing the treatment beam to ensure delivery of radiation coincides with a known position of the patient's internal anatomy (gating)
- ❖ Restricting variation in the position of internal anatomy

Pre-Requisites for Image Guidance-Geometric Verification

Imaging infrastructure

After consideration of the particular anatomical site, decide on a
clear method for image guidance, which will depend on the available equipment.

- 2D planar – MV, kV or magnetic resonance imaging (MRI)
- 3D volumetric – kV cone-beam CT (CBCT), megavoltage CT (MVCT), MRI or ultrasound
- 4D volumetric – kV-CBCT, MRI or Ultrasound
- External Anatomy Surface based

Information Technology & Networks

1.Connectivity with existing Diagnostic Imaging equipment and DICOM- Digital Imaging & Communications in Medicine

2.Fast – networks for imaging applications should support data transfer to at least 100 megabits/second and preferably 1 gigabit/second; images should be readily available consistent with the requirements of the particular workflow

3. Robust and reliable – information technology measures should be in place to guarantee sufficient up-time

4. Secure and able to maintain the integrity of reference and verification data.

5. Duplication of Image storage in Radiology systems, TPS, Local Area Network and Treatment console can be mitigated through PACS (Picture Archiving & Communication Systems)

Quality Assurance-

1.Image acquisition accuracy and consistency of image quality

2. Image processing: how does processing affect the end result (for example, CBCT reconstruction slice thickness, artefact suppression filters)?

3. Analysis techniques: how is the accuracy of registration affected by the parameters and methods used (for example, differences between algorithms used, region of interest [ROI] position and size)?

4. User accuracy and reproducibility: how do results vary between users, between repeat evaluations and between fractions?

5.Accuracy of displayed and performed shifts: how accurate is the displacement information given by each registration system and how accurately is the shift applied?

6.Safety: have all steps in the process been reviewed in order to identify all potential errors and have processes been designed to minimise the risk of errors occurring?

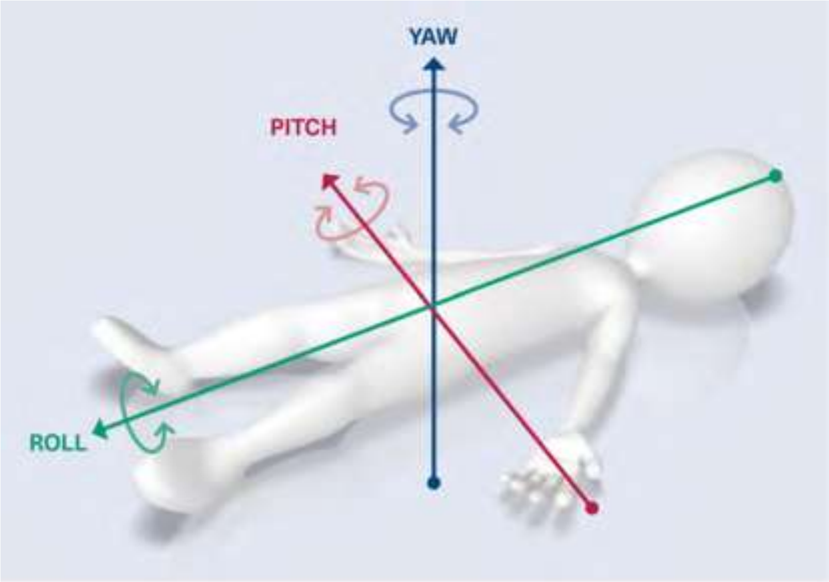
Consistency of co-ordinate systems, error reporting and corrective actions-

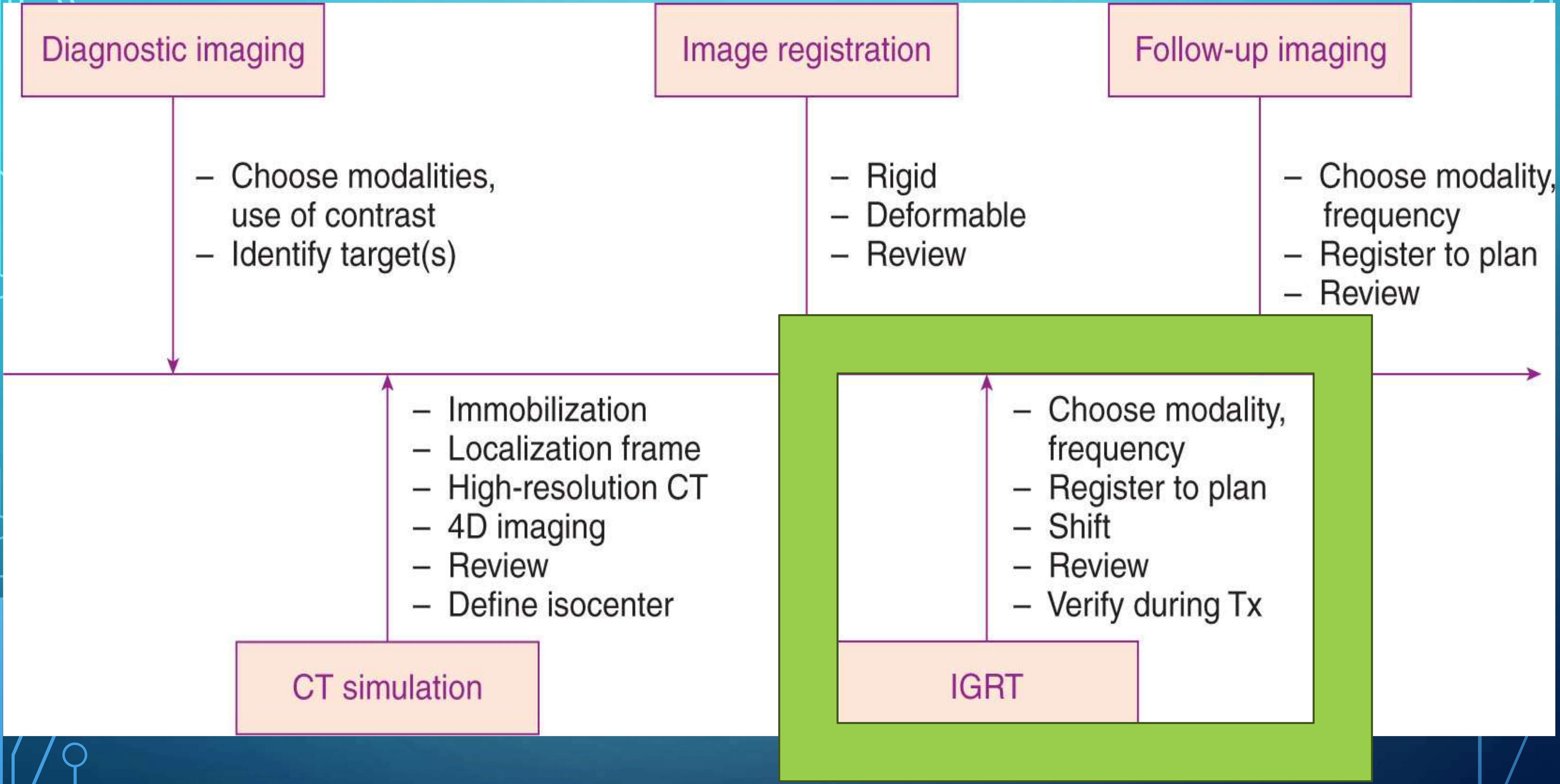
1.Single co-ordinate system –specifying the isocentre position relative
to set up point expressing translational direction & rotations along these axes

2.Protocol to specify the direction of movement & what to move-
couch or treatment field

3.Definitions of directions of rotation & their order should be properly defined

example- translations followed by yaw, roll & pitch is the convention for Hexapod-6-D correction table overlay.
OR
Rotation correction of yaw, pitch & roll followed by translation





Process map of Imaging for SRS/SBRT

The term Stereotaxy can be traced back to Platon and Euclid in the 4th and 3rd century BC, respectively.

There it was used in a manner that "stereon in stereotaxy came to mean '**spatial' or '3-dimensiona**l'.

Taxis is derived from the verb ***tattein (τάττειν)*** **with the meaning 'to position'.**


ЭНЦЕФАЛОМЕТРЪ.

Приборъ для опредѣленія положенія частей мозга у живого человѣка.

Проф. Московскаго Университета

Д. Н. Зернова.

Изготовленъ фирмою „Ө. Швабе" въ Москвѣ.

МОСКВА.

1892.

Ecephalometer by Zernov:
Device for localizing parts of brain in living humans. 1892
Moscow, Kandel & Shavinsky

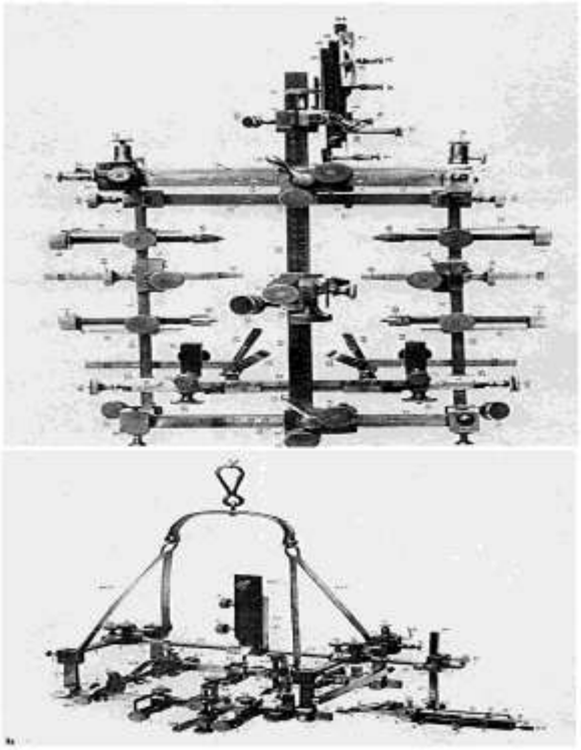
any technique that involves the recording and reproduction of three-dimensional haptic information or creating an illusion of depth to the sense of touch within an otherwise-flat surface.

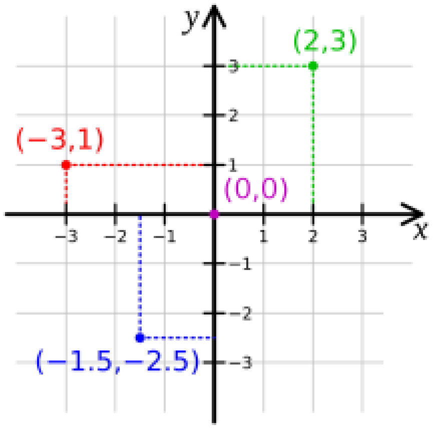
From: **Remarks upon the Term Stereotaxy: A Linguistic and Historical Note**

Stereotact Funct Neurosurg. 2015;93(1):42-49. doi:10.1159/000366490

The terms 'stereotaxis' and 'stereotaxic apparatus' were introduced by Clarke and Horsley in 1908 to denote a method for the precise positioning of electrodes into the deep cerebellar nuclei of apes.

The target in space was defined by 3 distances in relation to 3 orthogonal planes. Although this concept corresponded exactly to x-, y- and z-coordinates in a Cartesian coordinate system, Clarke never used the concept of coordinates.





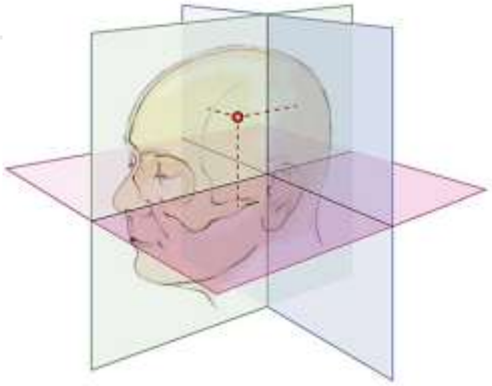
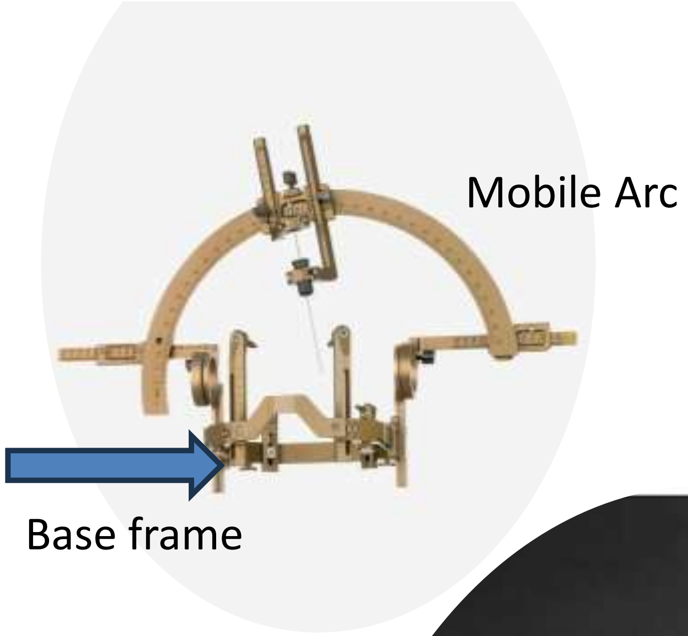


Image Guided Stereotactic Localization

- 1947-Lars Leksell introduced the arc-based frame consisting of a base frame & a mobile arc quadrant headpiece

- The design enabled the operator to place the target at the arc center and allow the target to be accessed at various angles.



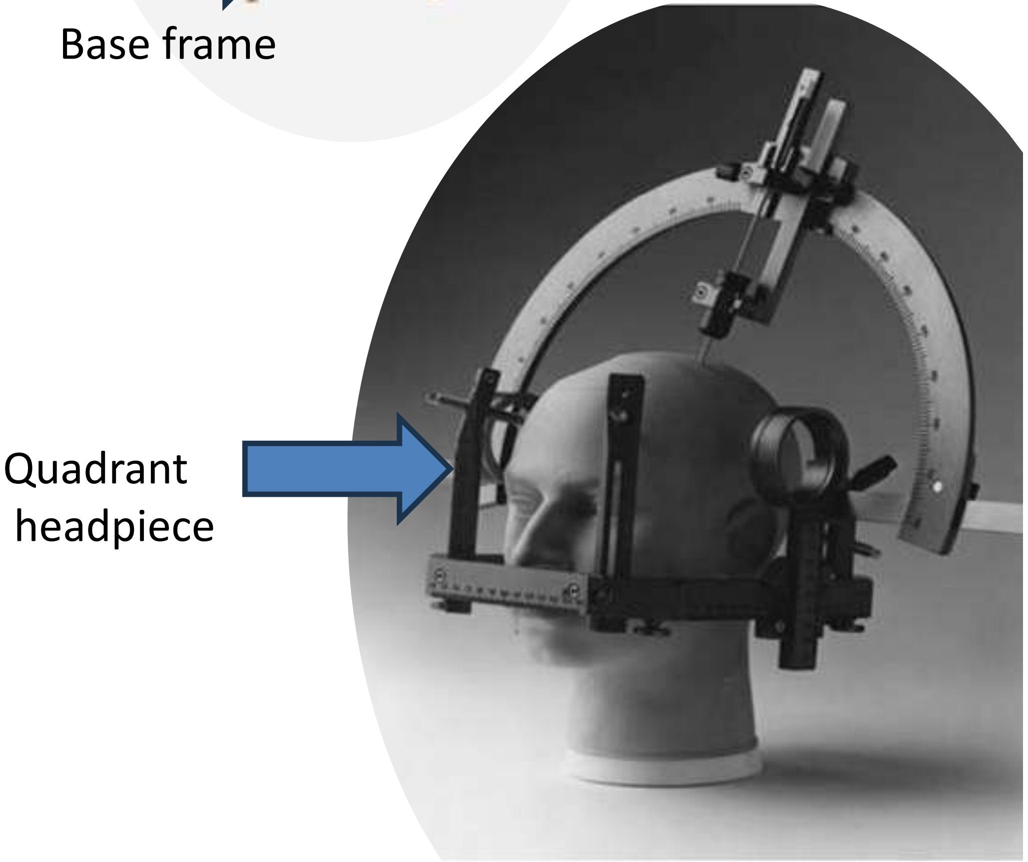
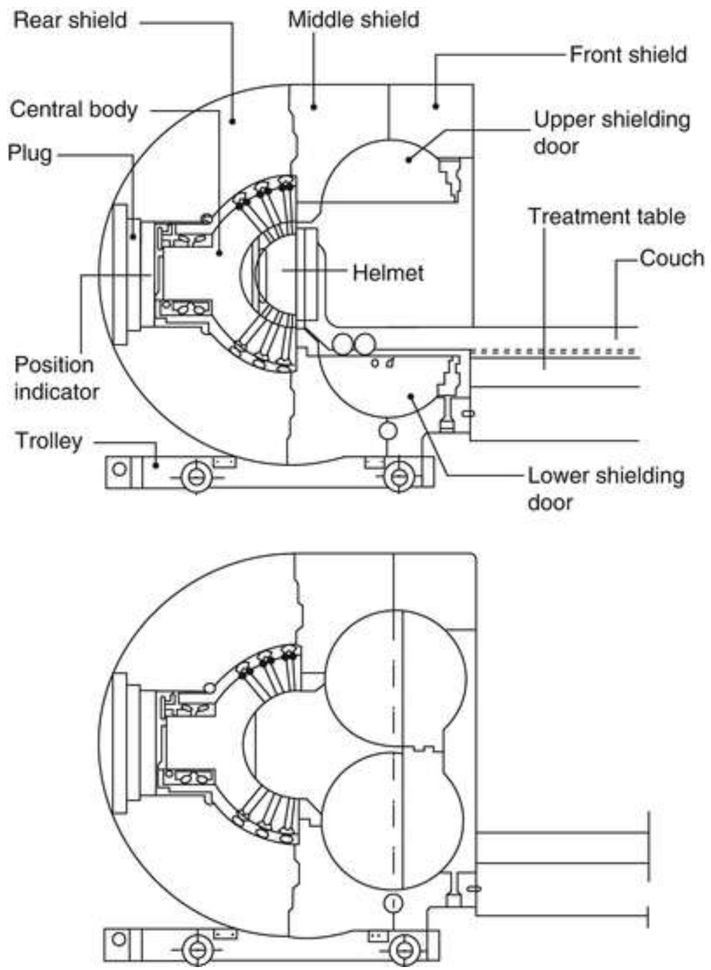
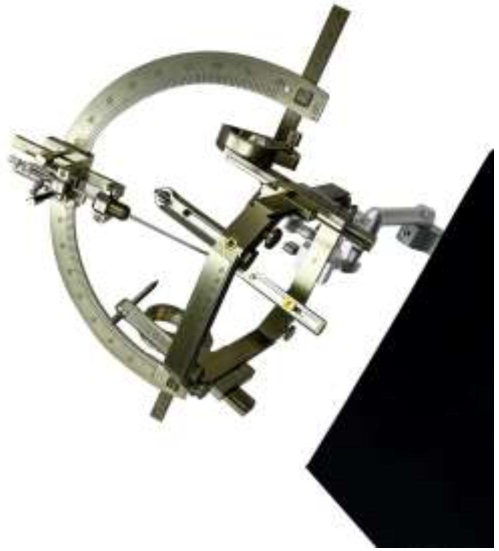
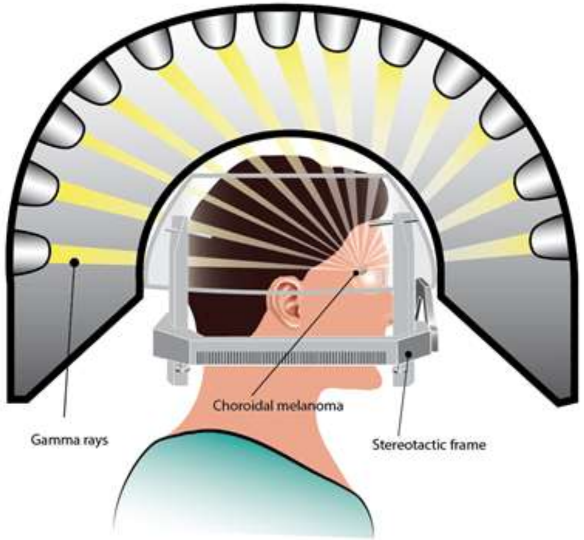


Image Guidance techniques for SRS







Fixation of stereotactic items (localizer and positioner) and definition of the reference point (0,0,0) of the stereotactic coordinates rely on stereotactic frame.

There is a constant geometrical relationship between the stereotactic frame and anatomical structures, such as Planning Target Volume (PTV) which is achieved by fixation of the frame to the patient's head.

Stereotactic Radiosurgery/Radiotherapy: A Historical Review. https://www.researchgate.net/publication/286104418

Leksell system (Elekta)

- Used for diagnostic and therapeutic stereotactic neurosurgery
- Compatible with gamma knife or LINAC platforms
- The arc employs the center-of-arc principle for encompassing the surgical target in three dimensions, enabling full access to any intracranial area

CRW system

- Simplified and improved form of BRW
- MRI compatible
- Its target-centered arc principle means that all arc trajectories pass to the target, thus obviating the need for fixed entry point
- Frame is affixed to cranium via four screws placed through graphite posts (red arrows). Outer cage (blue arrow) serves as a CT localizer for image registration

BRW system (Integra)

- Has set of vertical and diagonal rods (6 and 3) creating '**N**' shape alignment for stereotactic localization and alignment
- 4 pins into the skull
- Arc guidance frame – creates infinite pathways but for each trajectory, the computation must include entry coordinates.

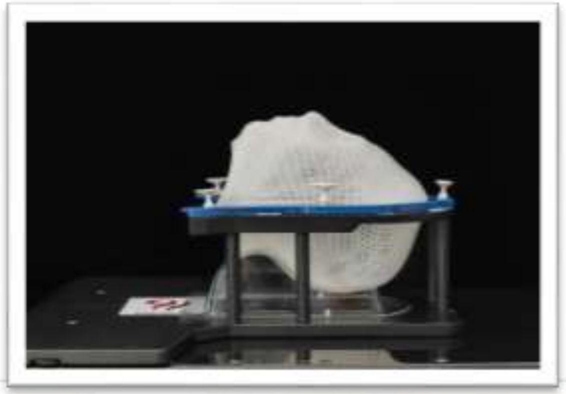
TALON (Best Namos)

- Removable head frame system for fractionated SRT
- Utilises two self-tapping titanium screws inserted into patient's skull at vertex
- TALON assembly is then attached to the screws on treatment table
- Frame can be removed after each fraction with two screws remaining in the patient's skull

Non-Invasive & Frameless SRS

GTC frame

Head Fix



Gill SS, Thomas DGT, et al,Relocatable frame for stereotactic external beam radiotherapy. Radiation Oncology Biol.Phys. 1991; 20: 599-603

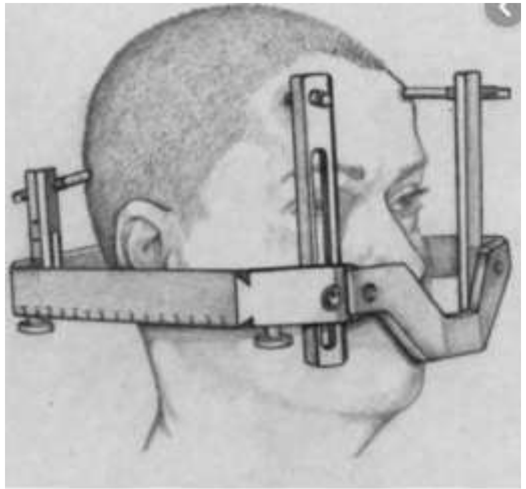
The systematic error with frameless SRS does not exceed 0.2mm for translational and 0.2 Deg for rotational displacements.

Almeida et al,
Positioning deviations in frameless and frame-based intracranial stereotactic radiosurgery.

Radiation Physics and Chemistry. Vol 167,Feb 2020,108363

Frame based SRS = Frameless + Realtime Verification + 6D Couch

Immobilization



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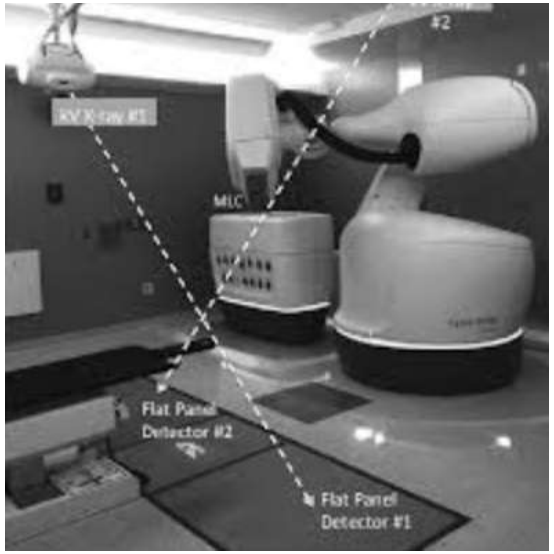
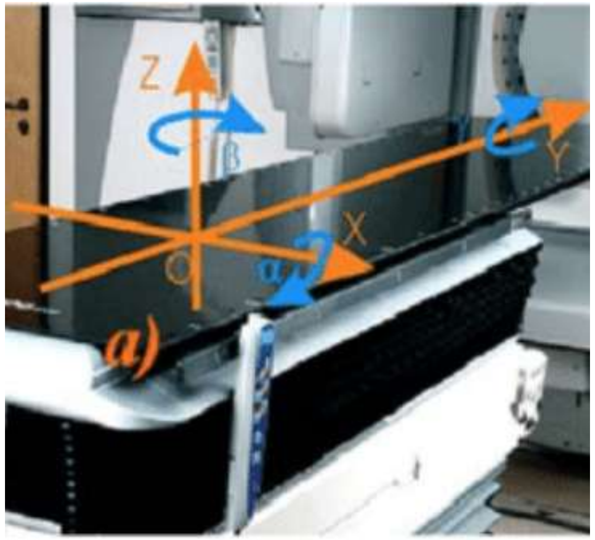
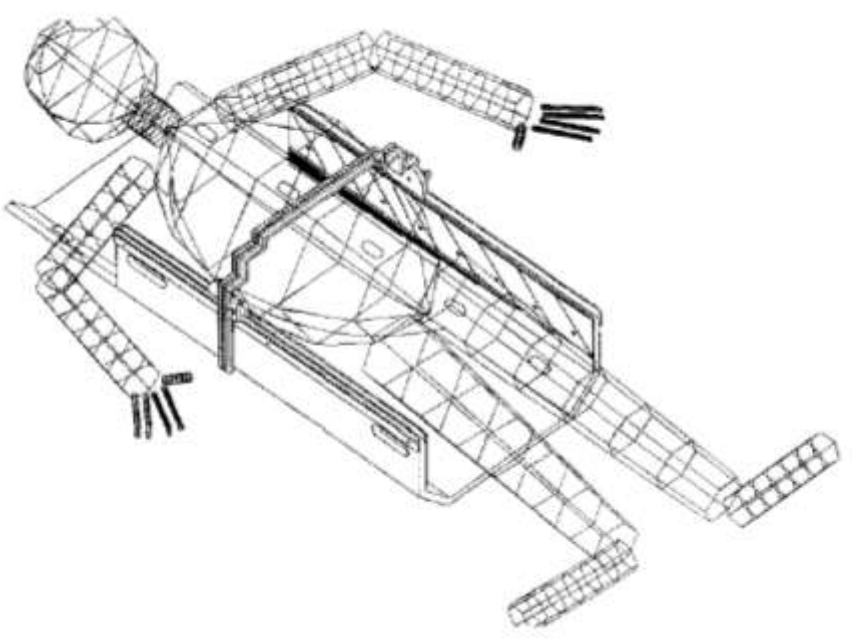
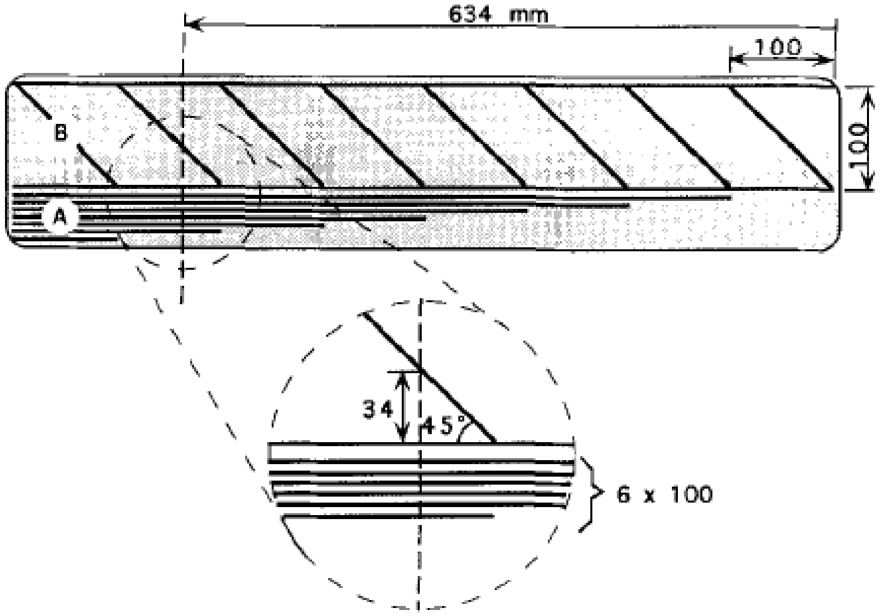




Real Time Verification

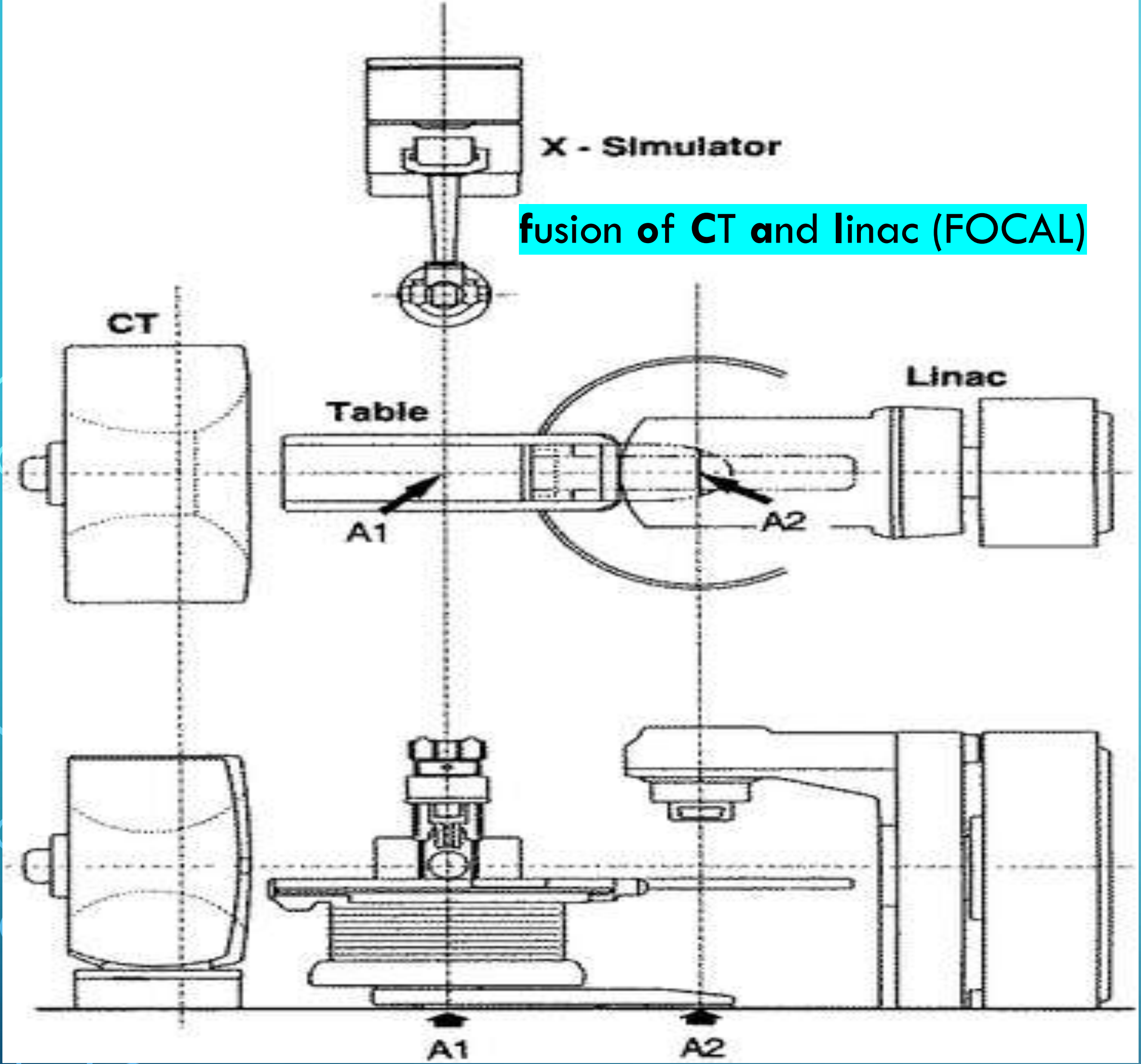


Schematic view of the sterotactic body frame and the position of the patient in the frame.

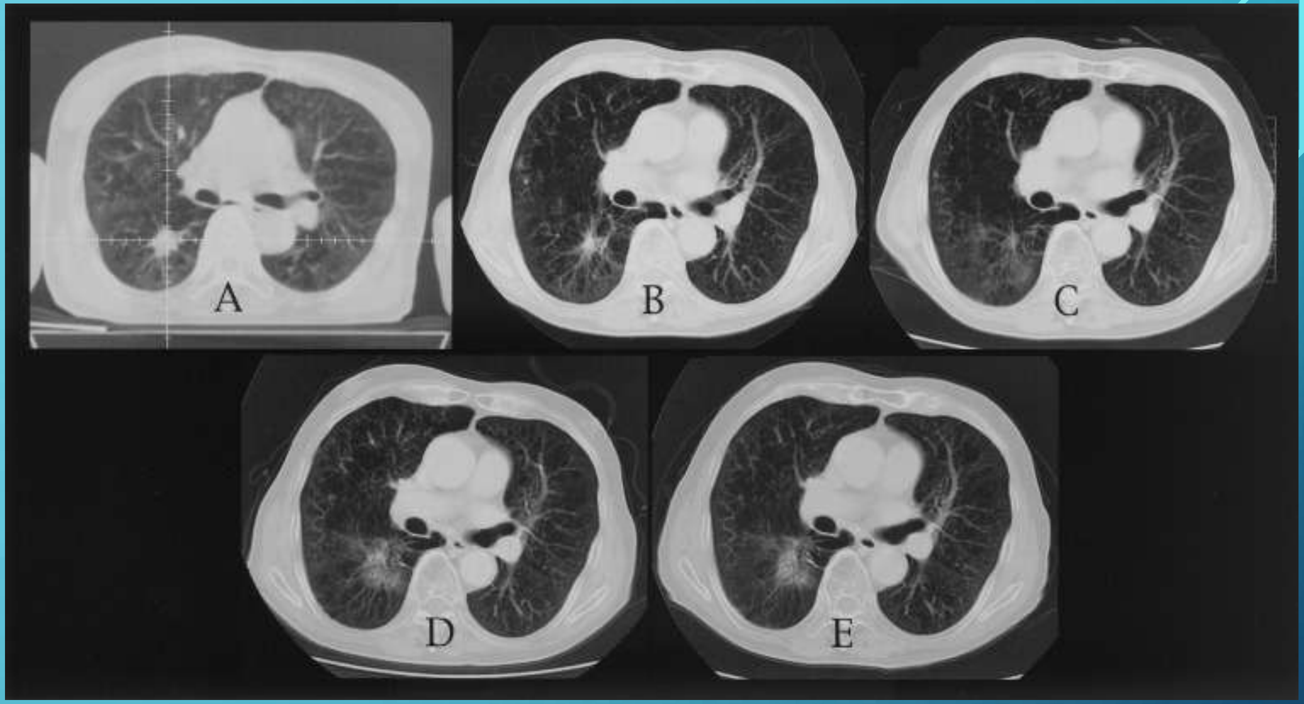


The construction of the longitudinal CT scale

Stereotactic Radiotherapy of Malignancies in the Abdomen: Methodological aspects Ingmar Lax, Henric Blomgren et al, Acta Oncologica, 33:6, 677-683, DOI: 10.3109/02841869409121782



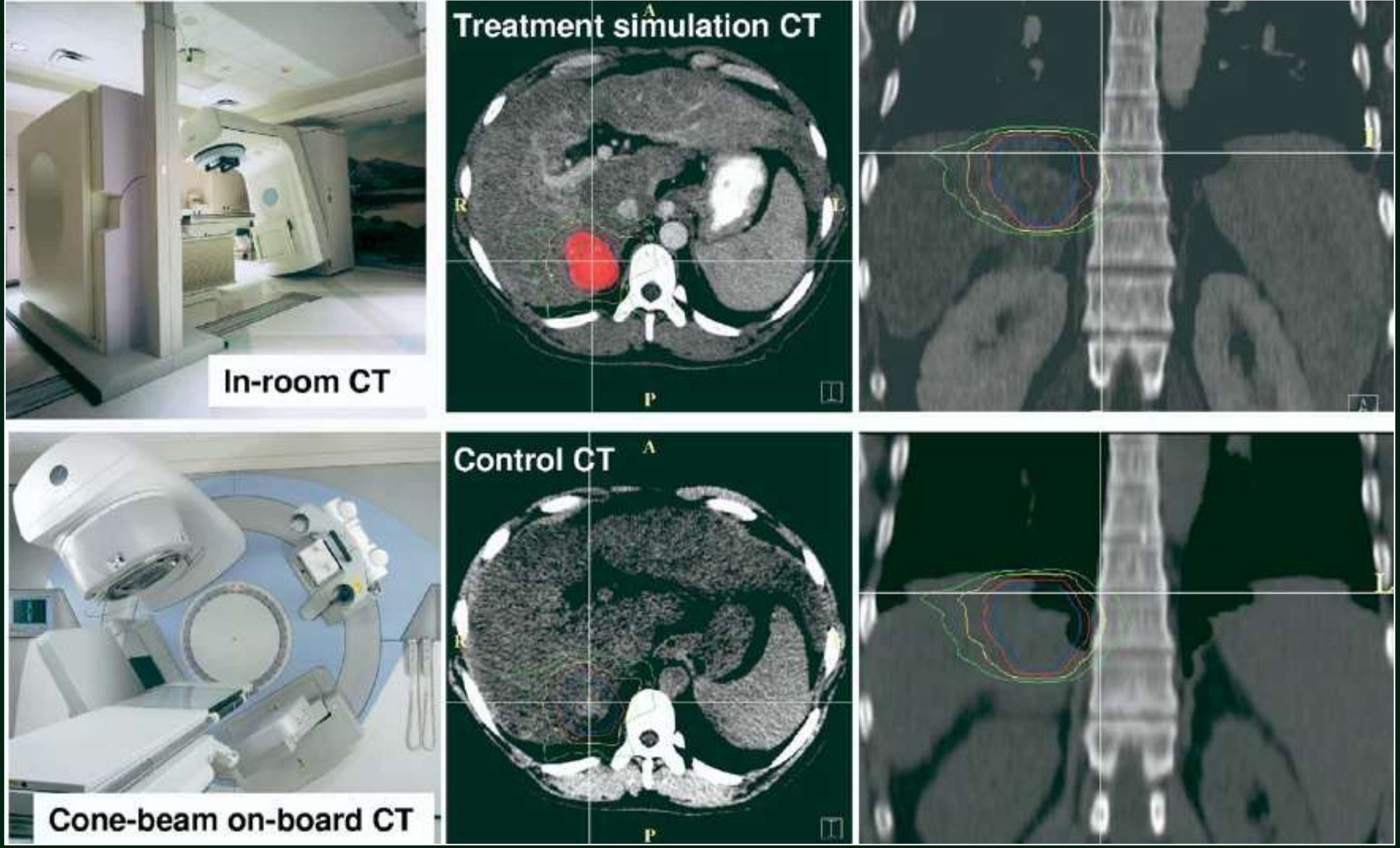
Fusion of CT and linac (FOCAL) unit. The gantry axis of the linac is coaxial with that of computed tomography (CT) and the X-ray simulator (X-S). The table has two rotation axes: A1 is for rotation between the three machines, and A2 is for isocentric rotation to make non-coplanar treatment arcs.



T1N0 M0 adenocarcinoma of the lung. (A) A 2.5-cm tumor is seen in the center image of the positioning CT scan on the treatment day. This CT image was scanned slowly (4 s/scan) with shallow respiration. SRT of 50 Gy in 5 fractions in1 week was given at the 80% isodose line of 3.5 cm in diameter. (B) Two months after SRT, (C) Fifteen months after SRT, the tumor disappeared. (D) Thirty-three months after SRT, a limited volume of radiation fibrosis was seen. (E) Forty-three months after SRT,

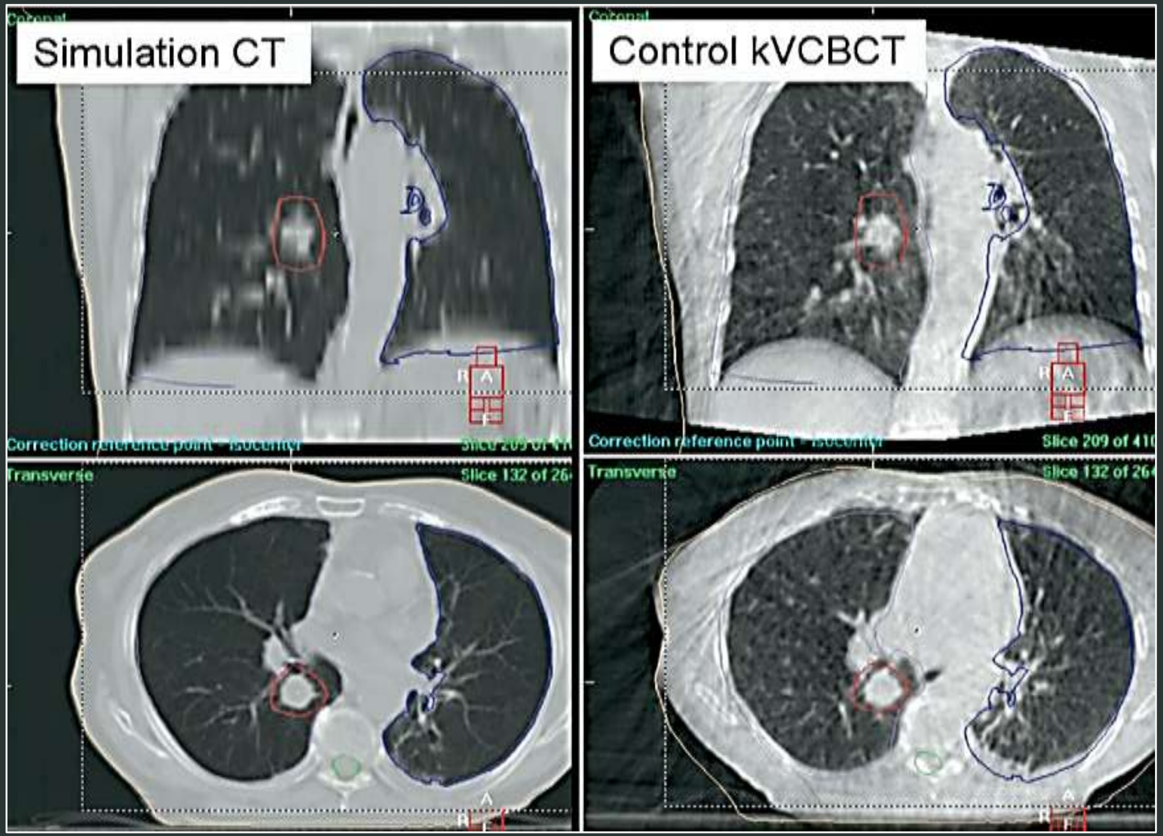
Minoru Uematsu M.D. et al 31 October 2000, Cancer

In-room CT unit linked by a rail system with the treatment couch and on-board Cone-beam CT unit mounted to the gantry of a linear accelerator Either unit would allow for image-guided targeting with the patient in treatment position.



The right upper figures show an original simulation CT with computed dose distribution and corresponding control CT before delivery of 1 of 3 radiation fractions for stereotactic body radiation therapy (SBRT) of a small HCC. The computed dose distribution has been superimposed onto the control CT scan to assess target volume coverage for the respective radiation fraction. Because the control CT was acquired without intravenous contrast, organ (liver) outline and bony structures may provide better guidance than the actual tumor volume.

Fuss et. al. Gastoentrology,2004;127:S206-S217



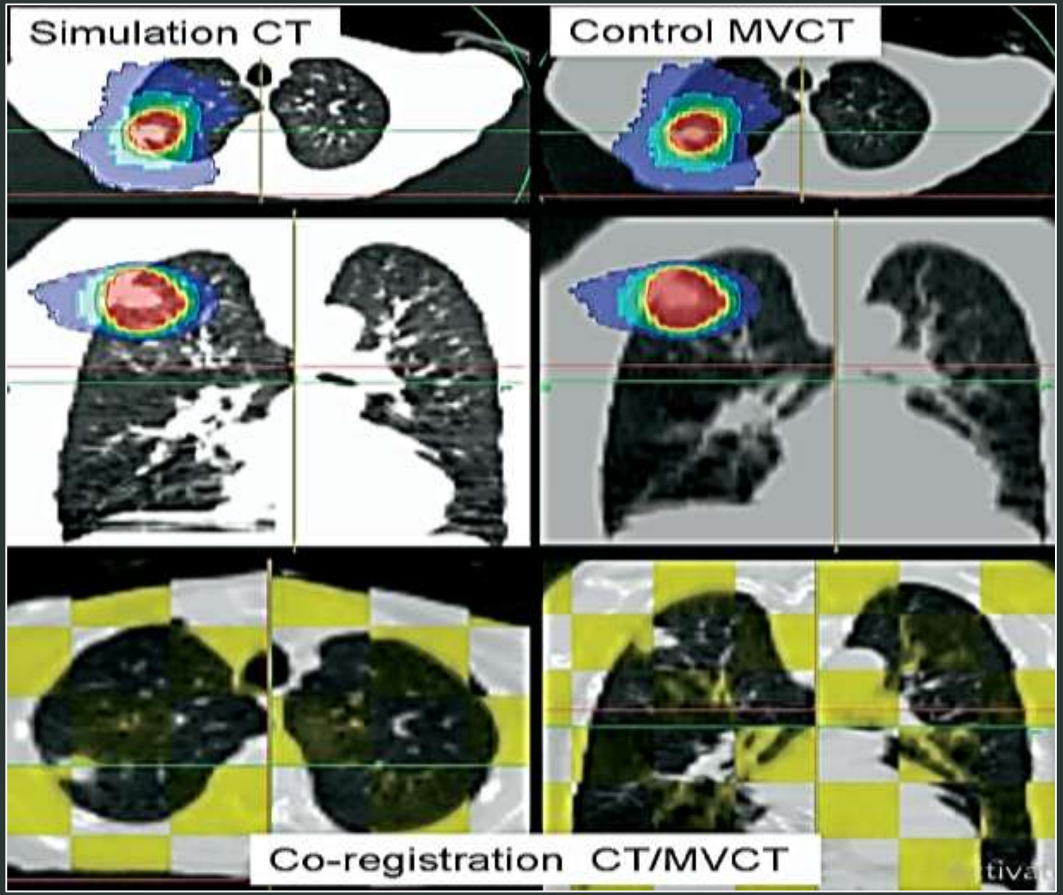
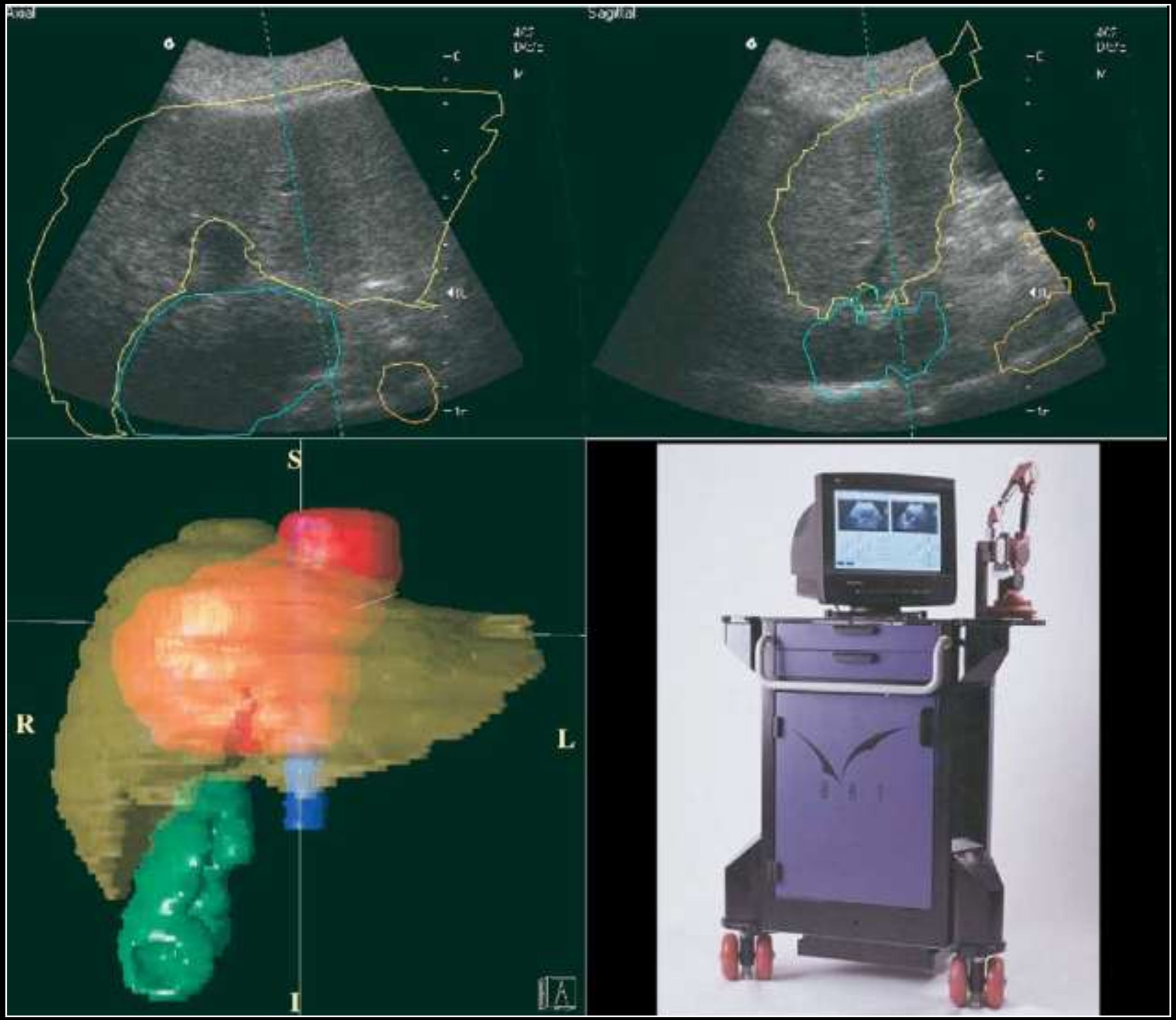


Image Guidance for SBRT-
Volumetric approach-KV CBCT-Taken in diagnostic CT with patient in SBRT –Body Frame with superimposition of PTV on control CT & MVCT Image Guidance

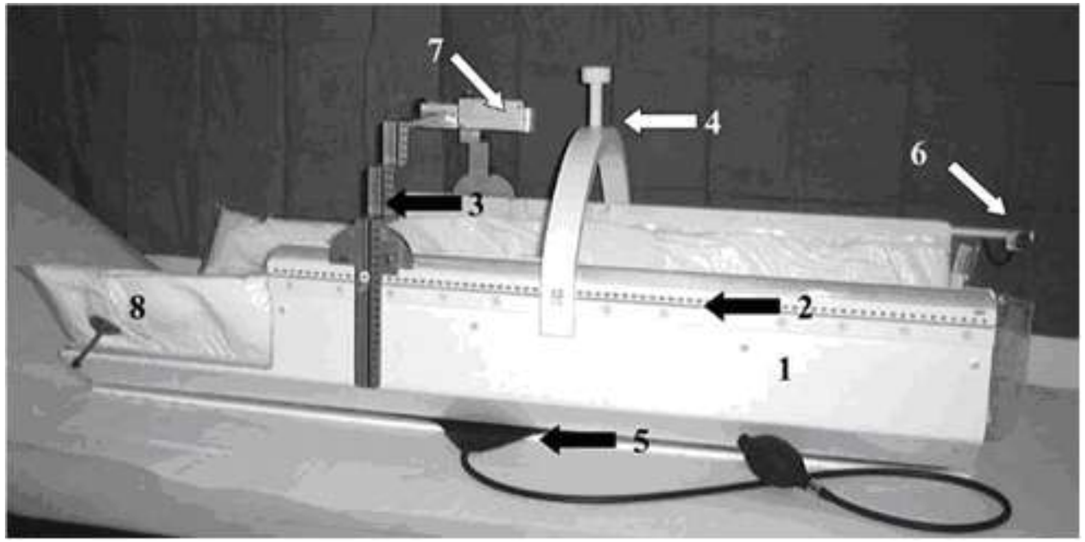
Fuss & Boda-Heggemann et al,Medical Dosimetry; 32,2 pp102-110,2007 FUSS et al

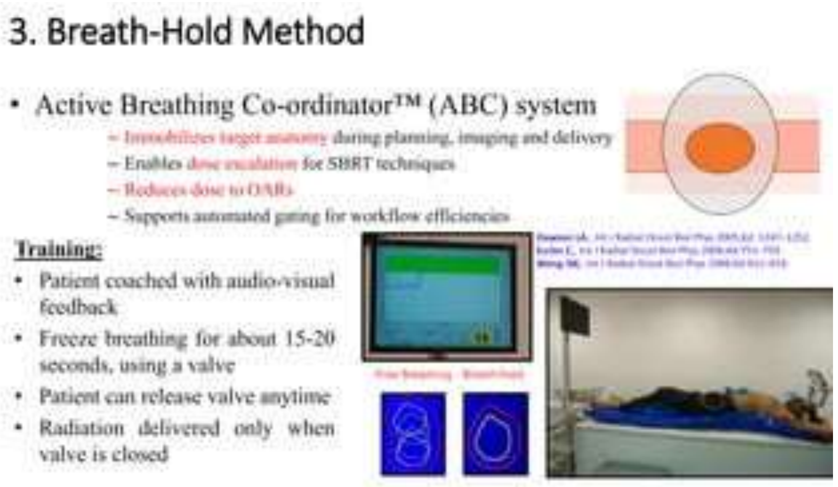


BAT ultrasound- based image-guided targeting device. The upper figures show outlines of CT-derived organ structures superimposed onto real-time acquired ultrasound images. Displayed are the outline of the liver and the target volume consisting of the HCC with inferior vena cava thrombus.

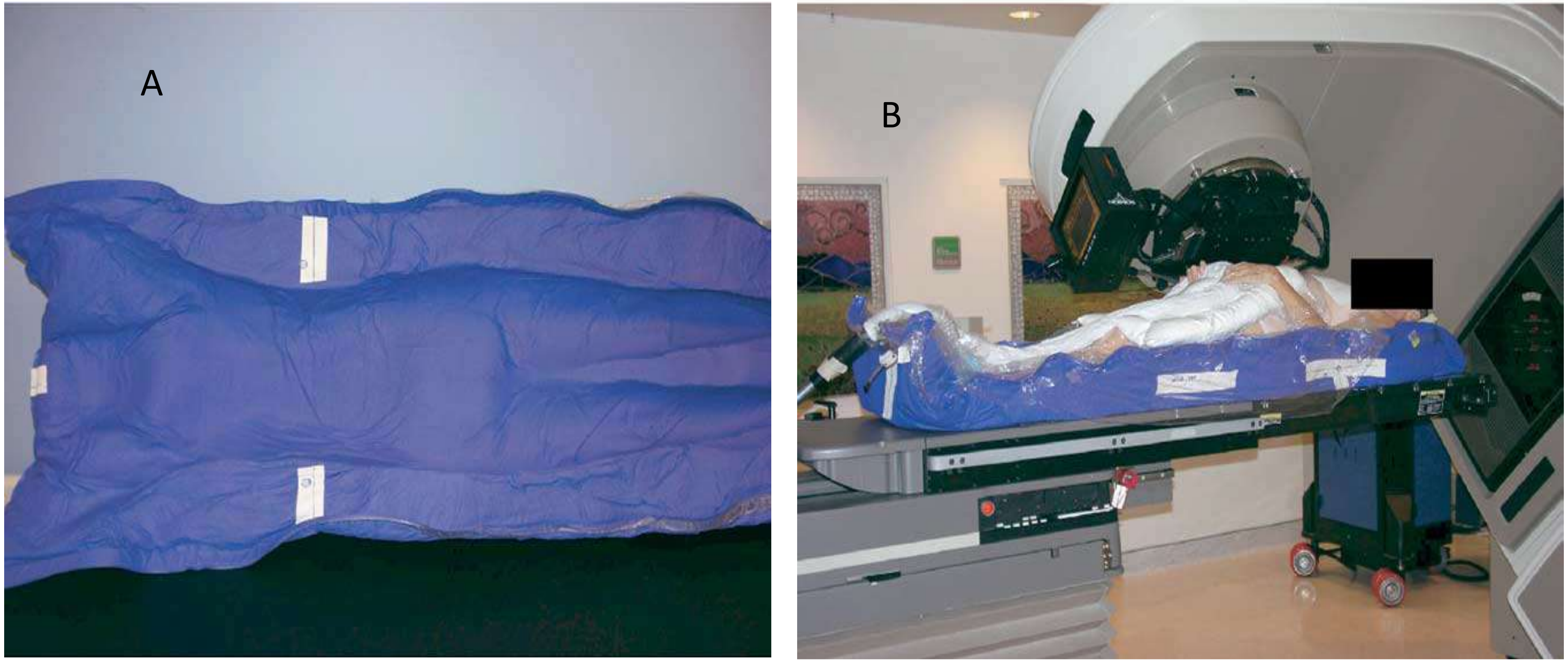
Fuss et. al. Gastroenterology,2004

Stereotactic Body Frame





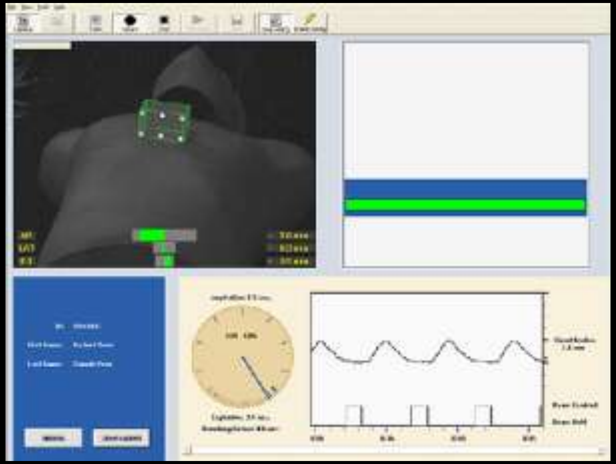
ANZAI belt system for Respiratory gating



Stereotactic body immobilization system. Figure A depicts the negative "vacuum cast" molded individually for each patient and providing for the required patient setup accuracy. Fig.B represents a typical patient setup for SBRT treatment on the linear accelerator table.

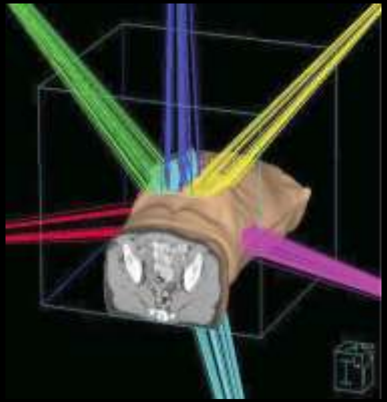
FRAMELESS SBRT FOR MOVING TARGETS

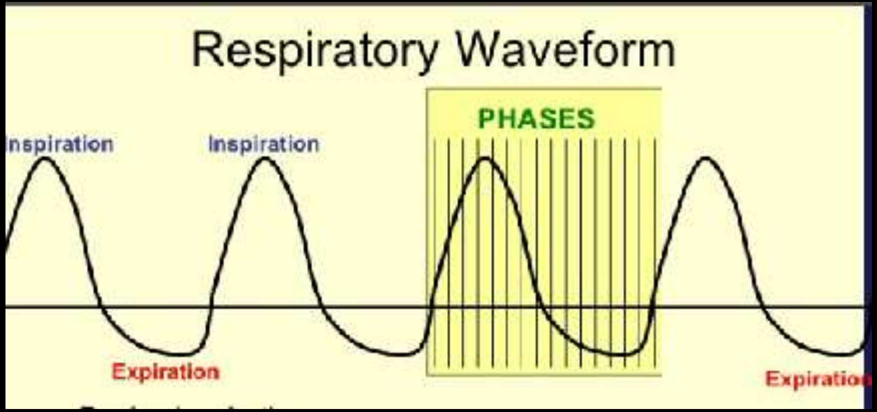
Real time Position Management(RPM)



Real Time Tracking

Deep Inspiratory Breath Hold





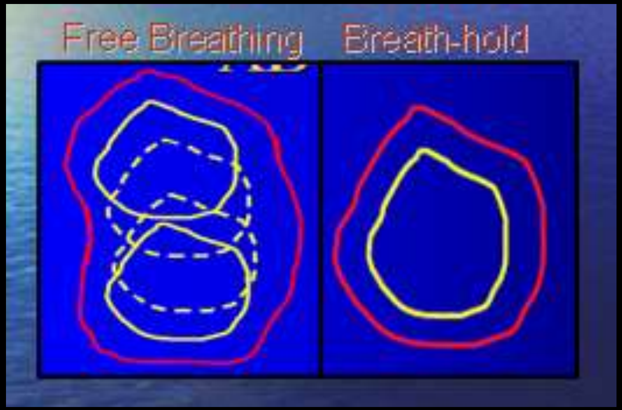


Image -Guidance Techniques

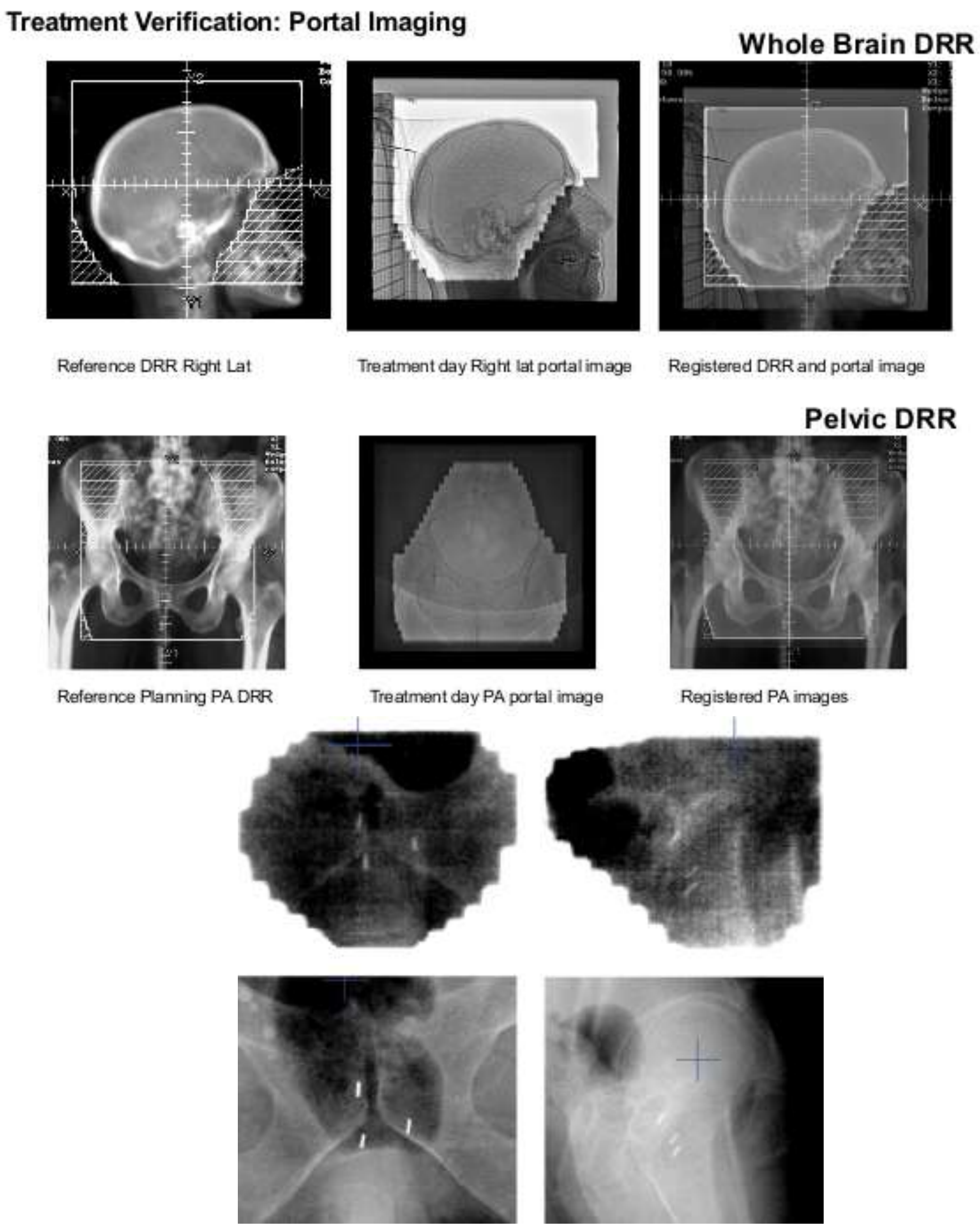
- PORTAL IMAGING
- Electronic Portal Imaging Device(EPID)
- Kilo Voltage Cone Beam CT (kVCBCT)
- Mega Voltage CBCT (MVCBCT)
- Mega Voltage CT (MVCT)
- IN ROOM KVCT
- In room Orthogonal X-Rays
- MR-Imaging

PORTAL IMAGING
kV or MV

- Patient positioning
- Block/MLC verification
- Field matching
- Gap verification

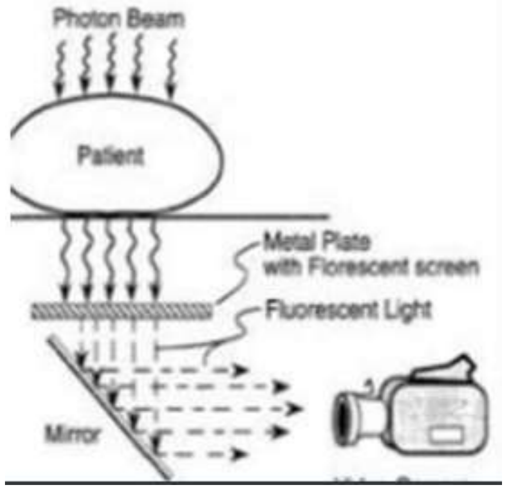
- Imaging involves double exposure in orthogonal direction for 3D correction

Lack of 3D anatomy information on target and OAR

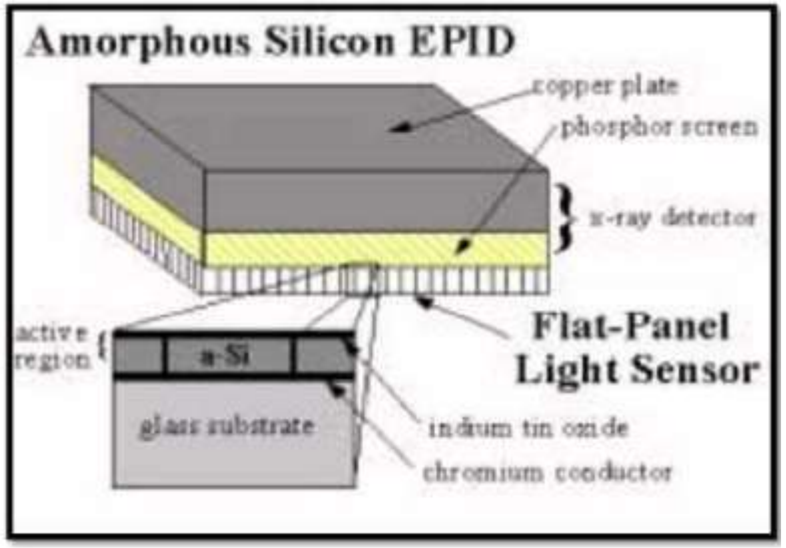


EPID-Image Guidance

- Electronic Portal Imaging Device (EPID) name given to Digital flat panel devices
- The first EPID system was video based.
- The beam transmitted through the patient excite a metal fluorescent screen.
- The analog output of the video camera is converted into a digital array with an ADC known as “ frame grabber ”.
- The spatial resolution depends on phosphor thickness.



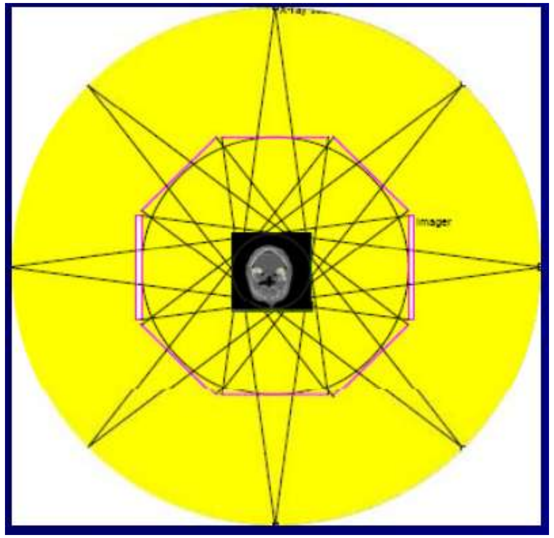
Another kind of EPID has a matrix ionization chamber system that consist of 256*256 liquid ionization chamber(scanning liquid ionization chamber-SLIC)
Amorphous silicon- based system
Within this unit a scintillator converts the radiation into visible light
The light is detected by an array of photodiodes implanted on an amorphous silicon panel

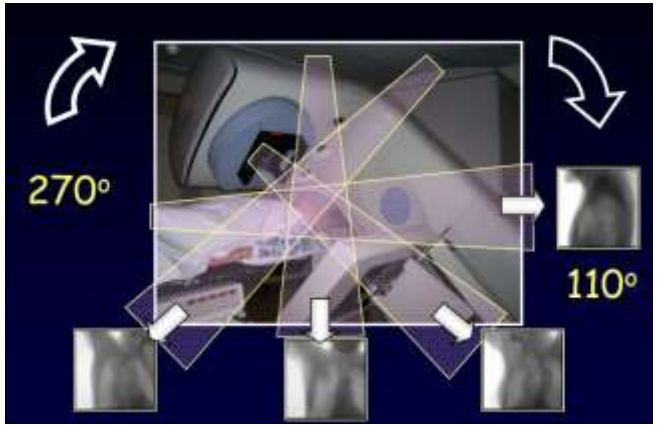


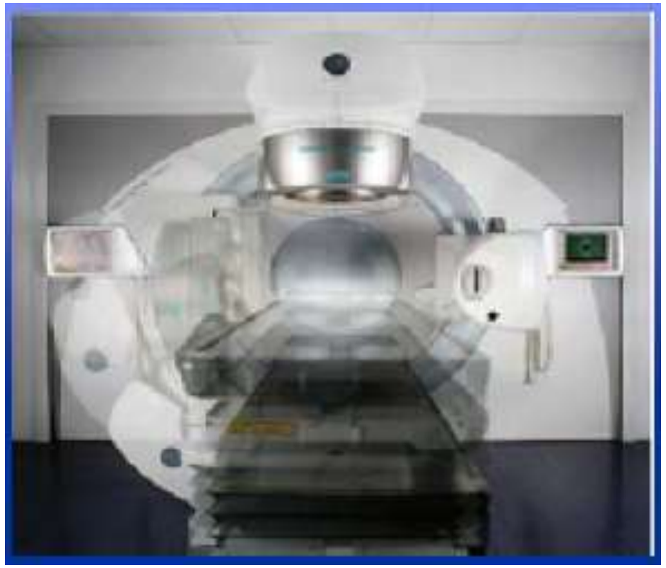
Cone Beam CT

1. **Kilovoltage x ray source or**
2. **The megavoltage therapeutic source**

- **KVCBCT system are generated by a conventional X- ray tube that is mounted on a retractable arm at 90 degree to the therapy beam direction.**
- **A flat panel of x ray detectors is mounted opposite to the x ray tube.**
- **It has ability to produce volumetric CT images with good contrast and submillimeter spatial resolution.**
- **Acquire images in therapy room coordinates**







X-Ray Volume Imaging (XVI)- or On Board Imaging (OBI) Image Guidance

- system has kV mounted source for 2D portal imaging and 3D CBCT
- **Small FOV = 27 cm**

Centre of panel in line with kV isocenter

All the object is in the image and can do half rotation

- **Medium FOV = 41 cm**

Panel offset 11.5 cm from isocentre

Image quality better in centre than the outside

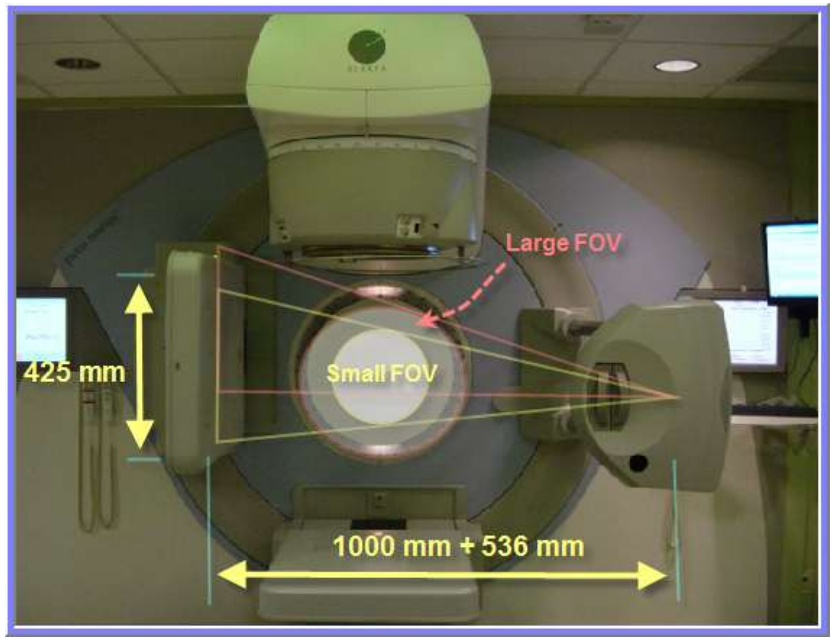
Require full 360 -degree rotation

- **Large FOV = 50 cm**

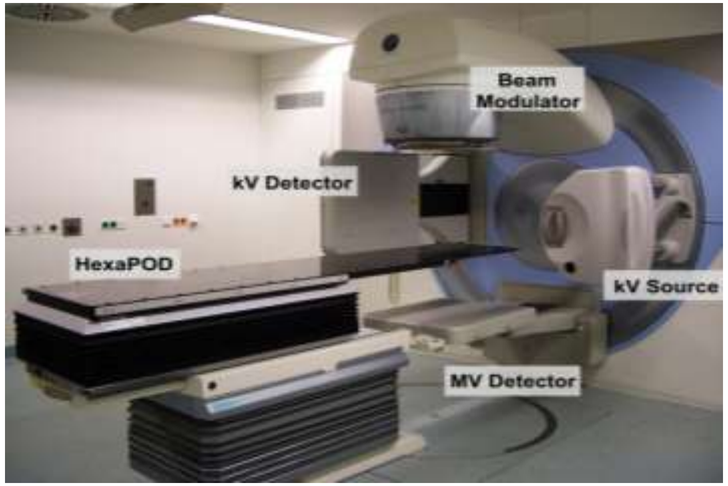
Edge of panel in line with isocentre

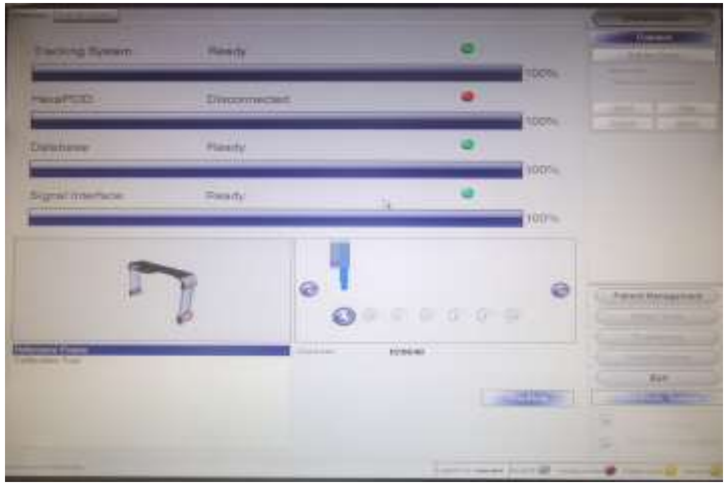
Half of object in each image

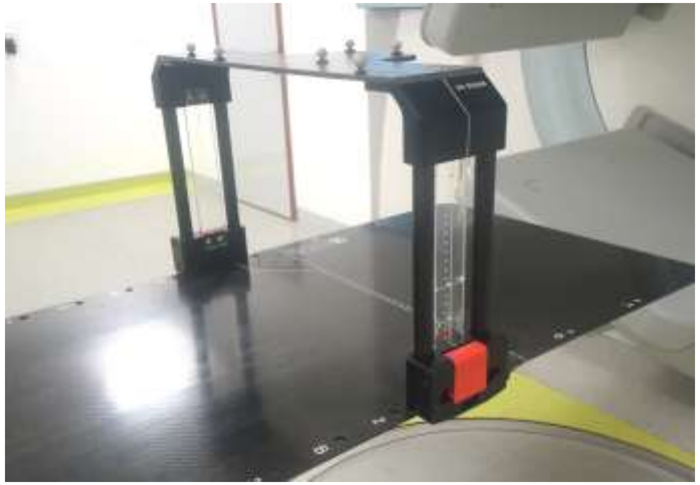
Require full 360- degree revolution

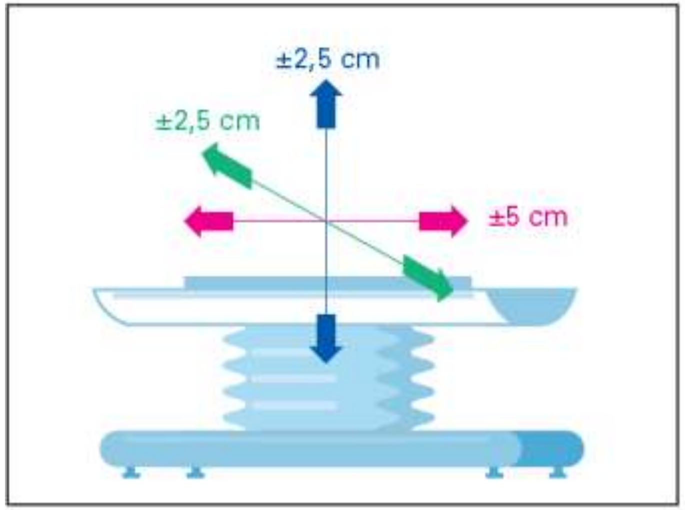


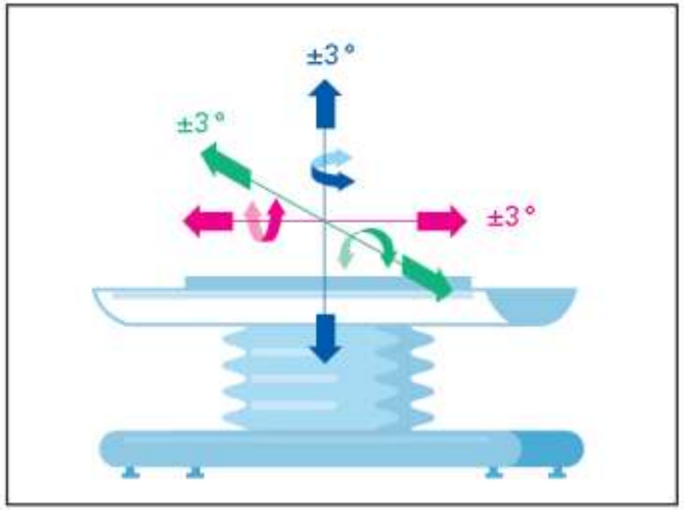
CBCT & HEAXAPOD Image Guidance







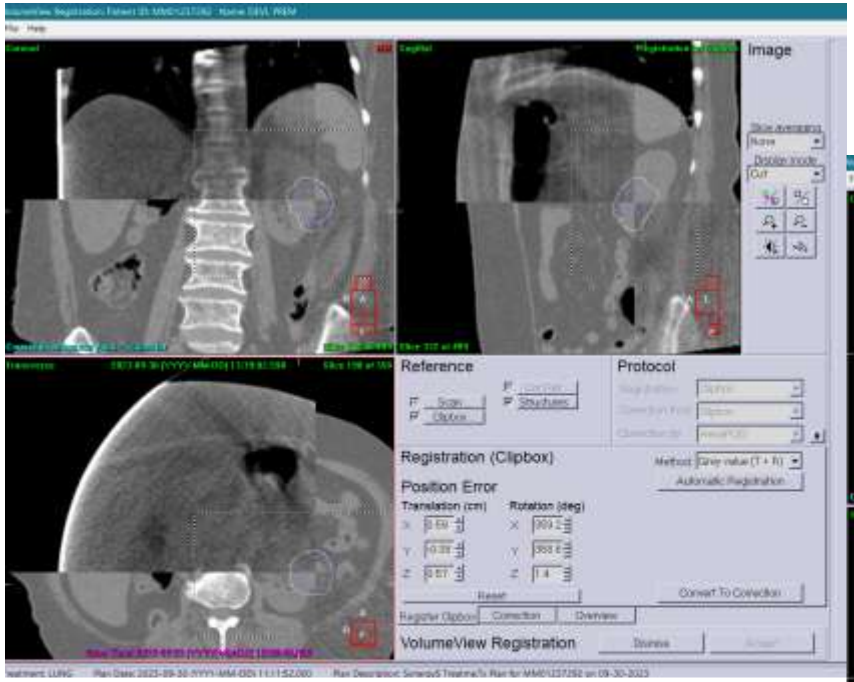




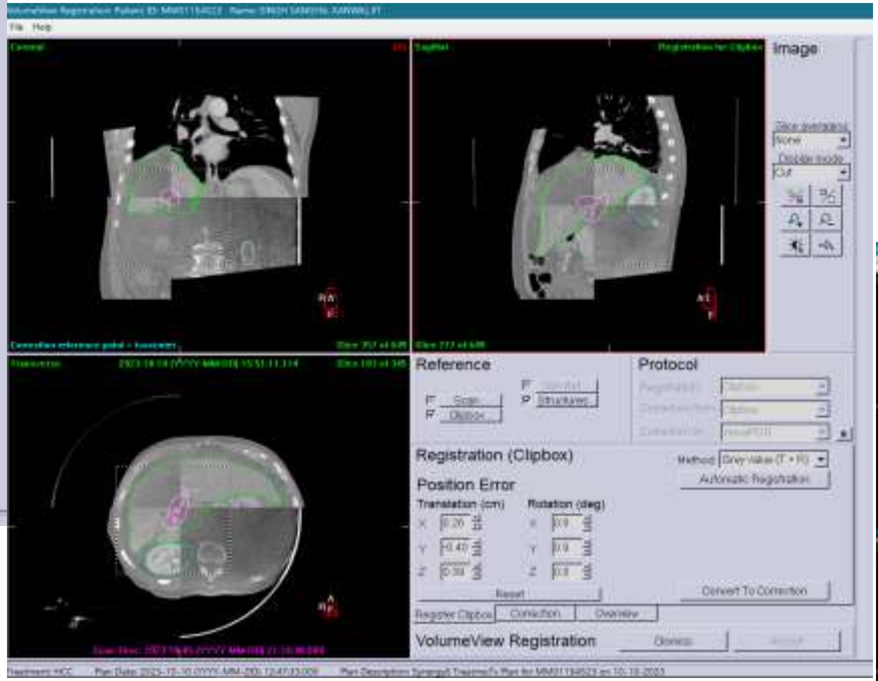
The HexaPOD evo RT couch top with 6 Degrees of Freedom

hree linear directions (X, Y, Z) and three rotational directions (ΘX, ΘY, ΘZ). Precision better than 0.1mm is required along with a load capacity of 200kg (440lbs) or above.

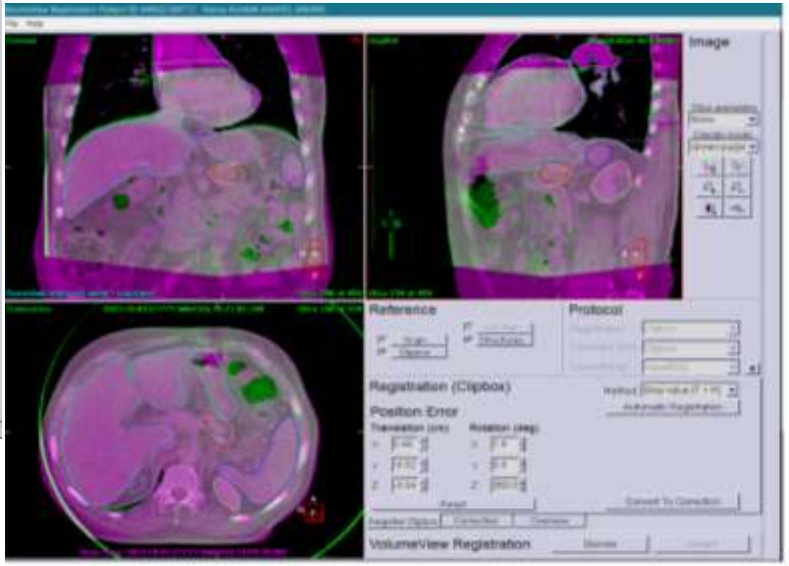
Active Breathing Co-Ordinator set up with XVI
Deep Inspiratory Breath Hold – SBRT



Renal Cell Carcinoma
40GY/5 fr

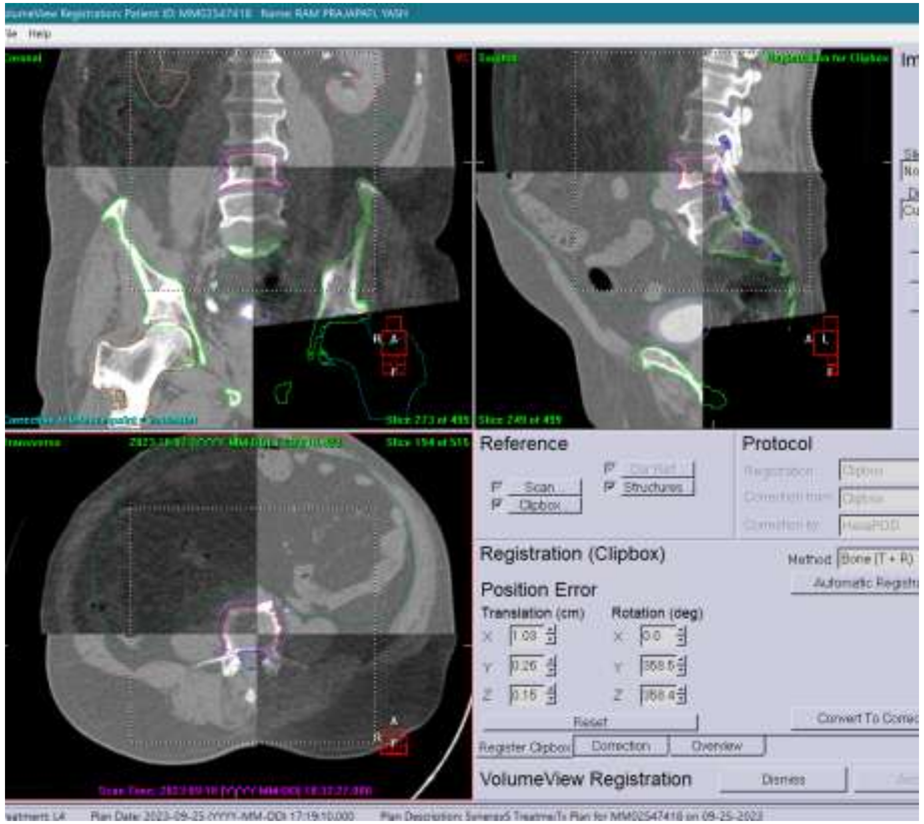


Portal Vein Tumour Thrombus-
Hepatocellular Carcinoma-48Gy/4 fr

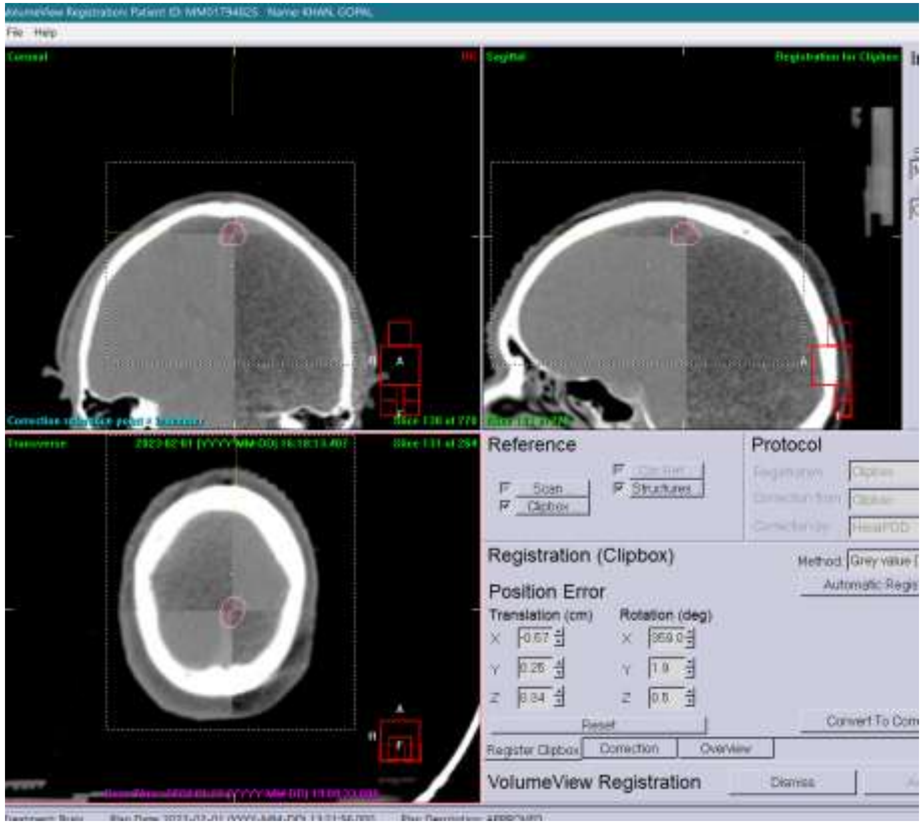


Carcinoma pancreas-40Gy/5 fr

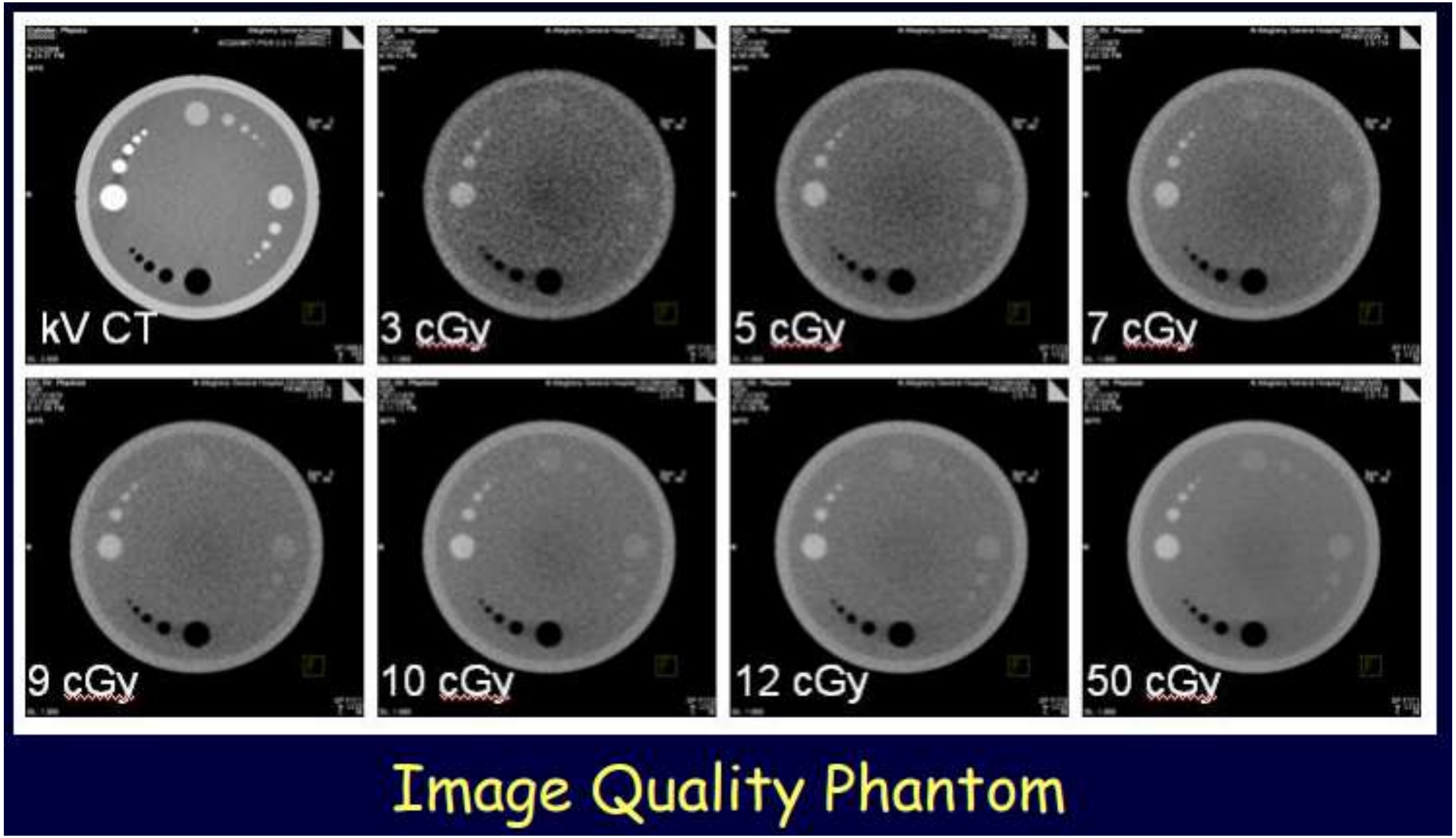
FRAMELESS SRS LINAC-Image Guidance with CBCT (XVI)



Lumbar Metastasis 24Gy/3fr



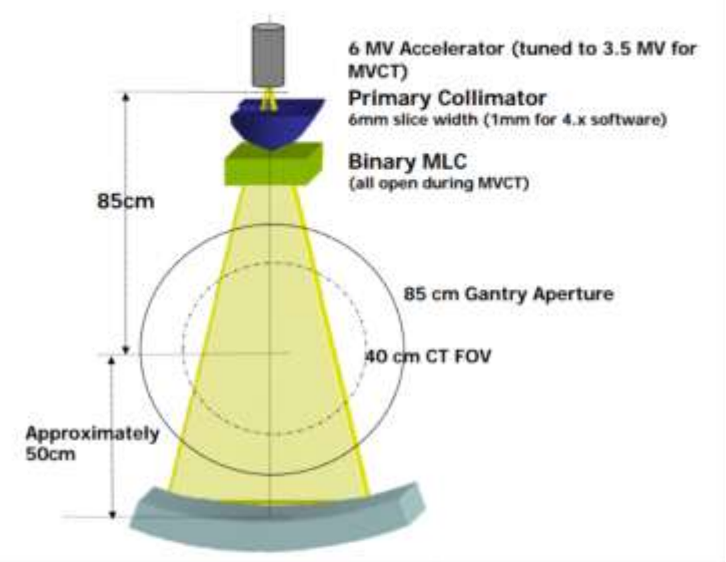
Brain Metastasis-20GY/1Fr

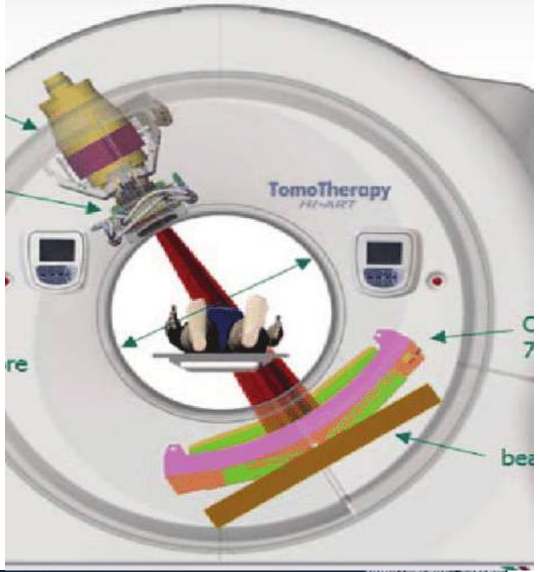


CAT PHAN PHANTOM –Complete characterization of multislice imaging performace for axial and spiral CT scanners FOR XVI

MVCT

- **Tomotherapy CTrue image uses photon beams of energy 3.5 MV for 3D MVCT**
- **Helical spiral CT**
- **3 choices of reconstructed slice thickness**
    - **Fine (2mm)**
    - **Normal (4mm)**
    - **Coarse (6mm) Coarse (6mm)**
- **Gantry Period = 10 sec**
- **Couch speed:**
- **Fine = 4 mm/rotation**
- **Normal = 8 mm/rotation**
- **Coarse = 12 mm/rotation**
- **Dose – 1 to 3 cGy**





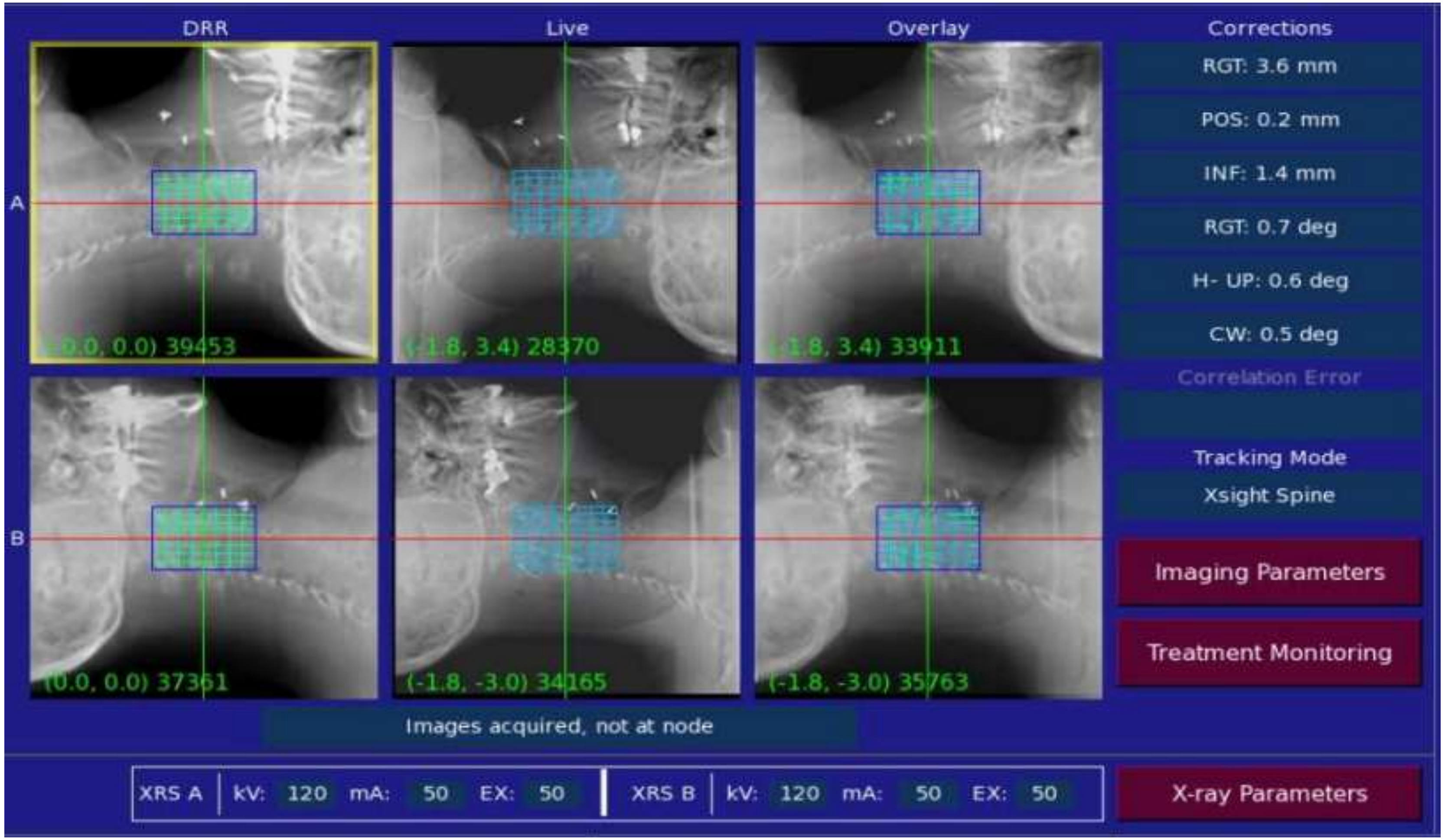
Synchrony


X-ray Sources
Linear Accelerator
ROBOTIC DELIVERY SYSTEM
IMAGING SYSTEM
Manipulator
TARGETING SOFTWARE
Image Detectors

What is 6D Skull tracking-Real Time Image Guidance

- Automated tracking method for patient alignment and position correction during cyberknife intracranial surgery.
- Bony anatomy of the skull is used as reference for tracking (eliminates need of invasive head frame).
- Based on rigid transformation
- Use to treat Cranial lesions like Brain metastasis ,Acoustic Schwannomas, Arteriovenous Malformation(AVM), Trigeminal Neuralgia, Meningioma etc.

X-sight Spine : Image Guidance

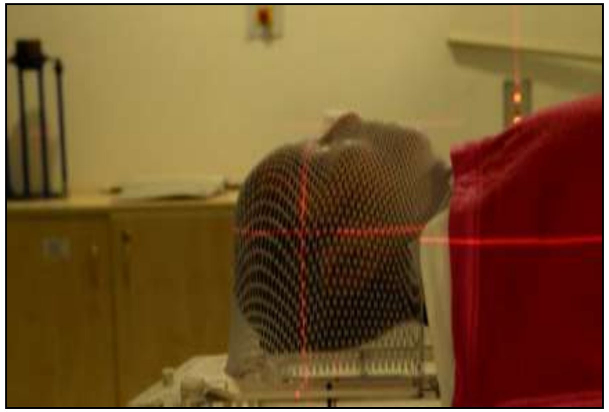


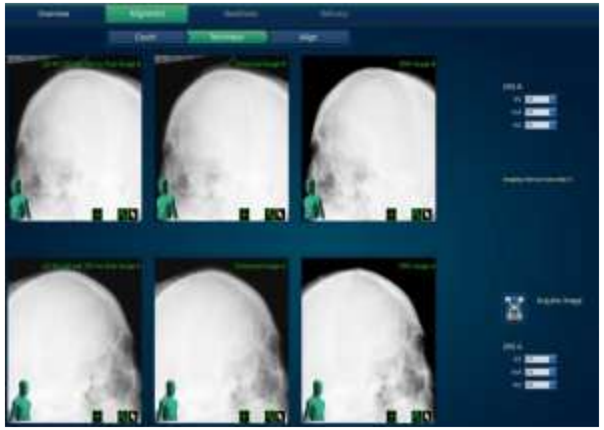
1. Robotic Manipulator Arm Corrections-
Mechanical accuracy of robot = 0.12mm and If target moves with respiration= 0.7mm

2. The DRR & real time X-Ray image are matched by image intensity & Brightness gain - between 0.98-1.02

3. Patient displacements are calculated for each acquisition vis a vis Alignment vs Imaging centre.

Treatment Delivery





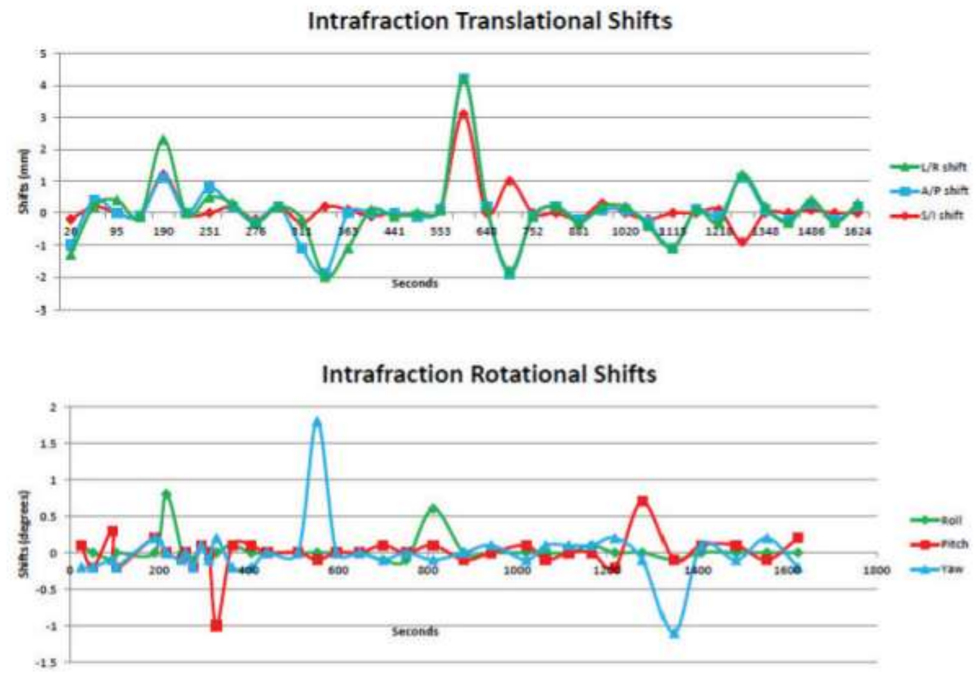


Figure 1. Intrafraction translational and rotational shifts plotted against time, for a treatment fraction.
SRS: Stereotactic Radiosurgery; SRT: Stereotactic Radiotherapy
L/R: Left-Right, A/P: Antero-Posterior, S/I: Supero-Inferior

Jour. of Radiosurgery and SBRT, Vol. 4, pp. 203-212
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PHYSICS INVESTIGATION

Analysis of intrafraction motion in CyberKnife-based stereotaxy using mask based immobilization and 6D-skull tracking[1]

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(Received: January 16, 2016; Accepted: July 25, 2016)

Purpose: Analysis of intrafraction motion in patients with intracranial targets treated with frameless, mask based stereotactic radiosurgery / radiotherapy using standard couch and 6D-skull tracking on CyberKnife.

Materials and methods: Twenty-seven treatment datasets of fifteen patients were analyzed. For each sequential pair of images, the correction to the target position (position "offset") in six-degrees of motion was obtained. These offsets were used to calculate intrafraction shifts, and their statistical distribution. PTV margins were calculated, based on Van Herk formula.

Results: The mean ± 1 SD intrafraction translationals were 0.27±0.61mm in left-right, 0.24±0.62mm in antero-posterior and 0.14±0.24mm in supero-inferior direction, and rotations were 0.13±0.21 degrees roll, 0.18±0.25 degrees pitch and 0.28±0.44 degrees yaw. Most intrafraction shifts were ≤ 1mm and 1 degree. Fourteen instances of intrafraction shifts exceeding the robotic correction threshold were noted. Calculated PTV margins were 1mm, 1mm and 0.4mm for for left-right, antero-posterior and supero-inferior directions, respectively.

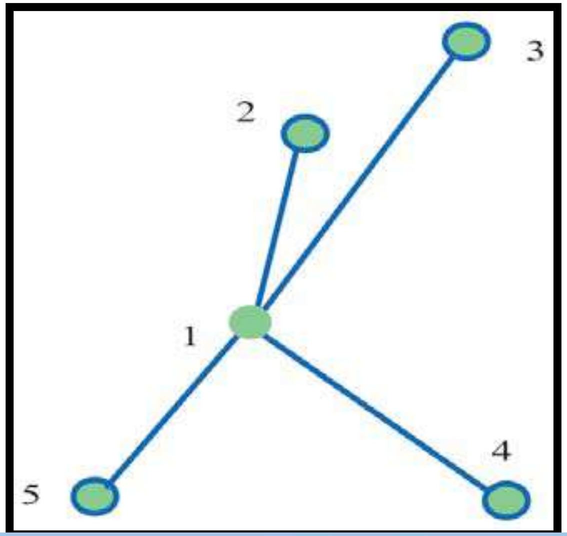
Conclusions: CyberKnife 6D-skull tracking with 1mm PTV margin effectively compensates for intrafraction motion. The occasional large intrafraction movements may assume significance for techniques not employing intrafraction motion management.

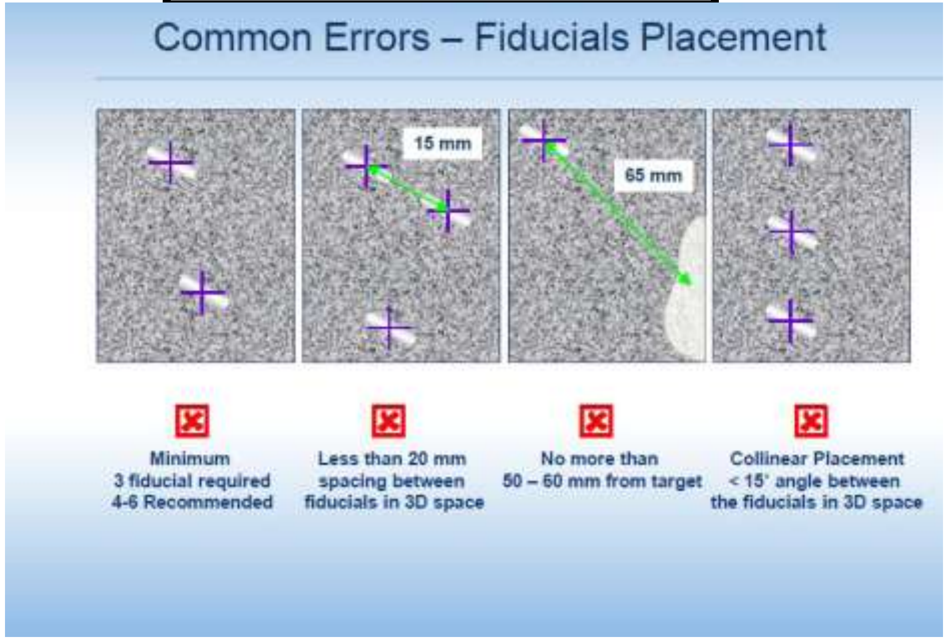
Fiducial –Image Guidance

- Gold fiducials.
  - Diameter 0.7mm to 1.2mm
  - Length 3mm to 6mm

- Minimum distance - 2.0 cm between fiducials.

- Maximum Cube size-6cm x6mx6cm
- Non-collinear placement
- A minimum 15- degree angle between any grouping of 3 fiducials should be used.
- Ensure that all fiducials can be visualized in 45 deg oblique views with no overlap.
- Using 3 or more fiducials significantly improves targeting accuracy.





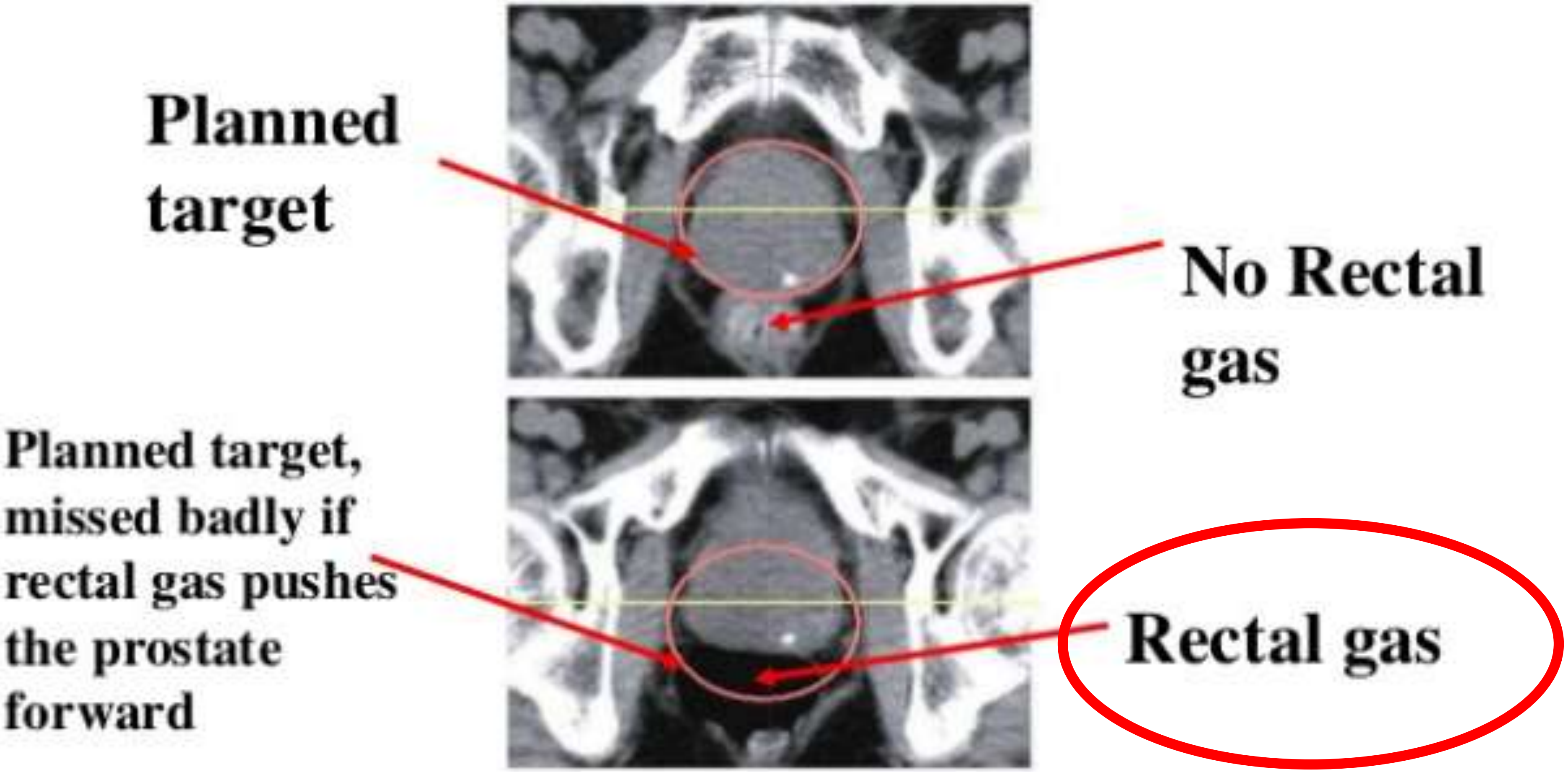
<u>Fiducial Based Image Guidance</u>

1. Pancreas
2. Liver
3. Prostate
4. Soft Tissue Sarcoma > 6 cms from Centre of Vertebral Body

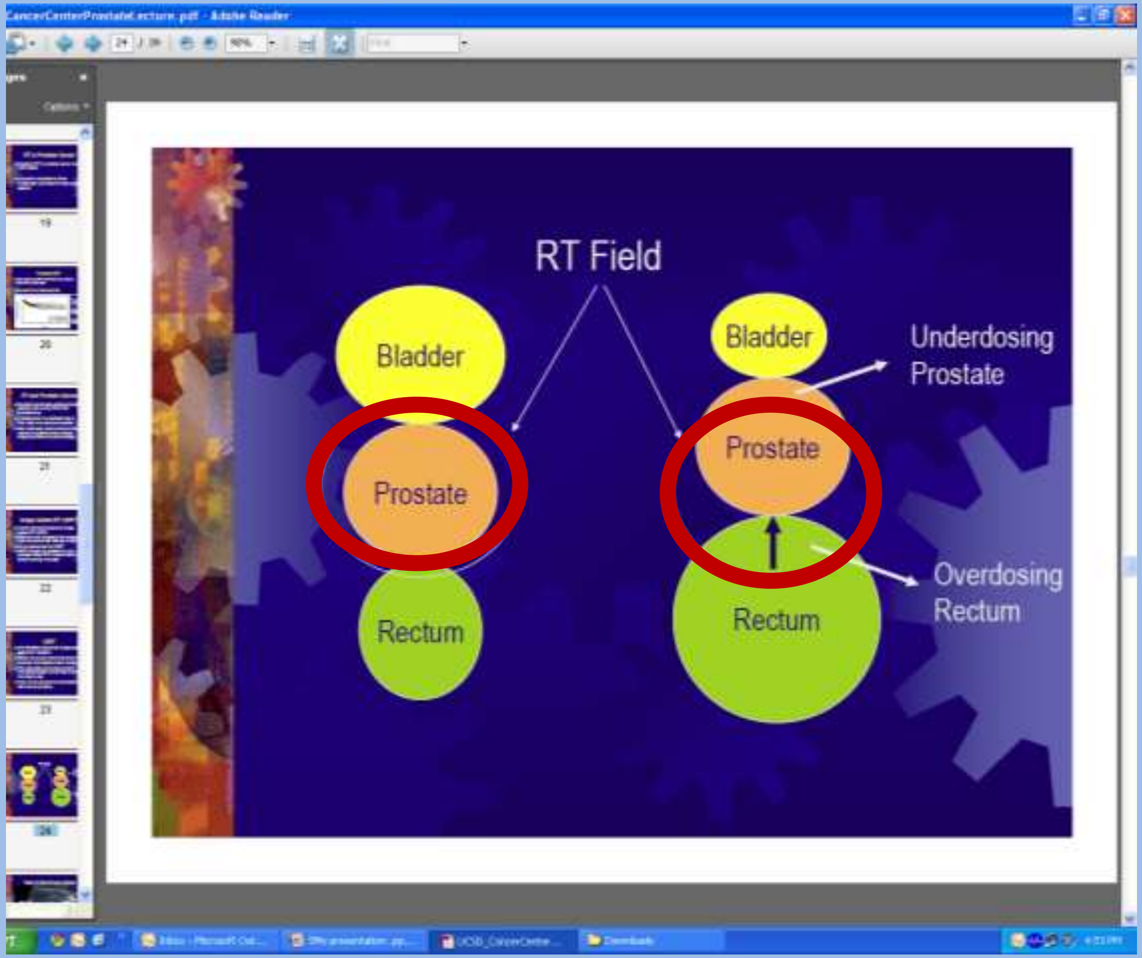
6.Pelvic Node Recurrence

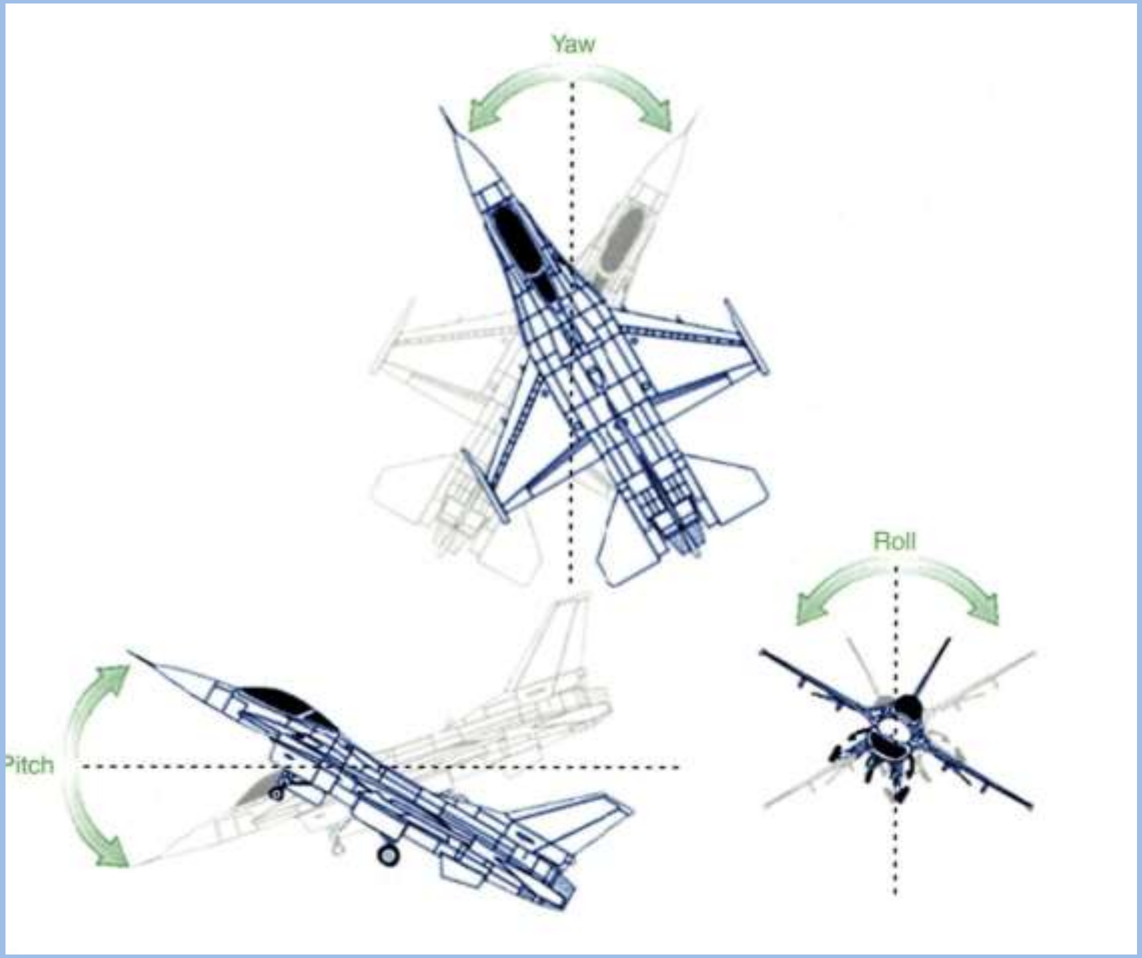
7. Rectal Cancer Recurrence

There is significant movement of the prostate gland based on daily gas in rectum

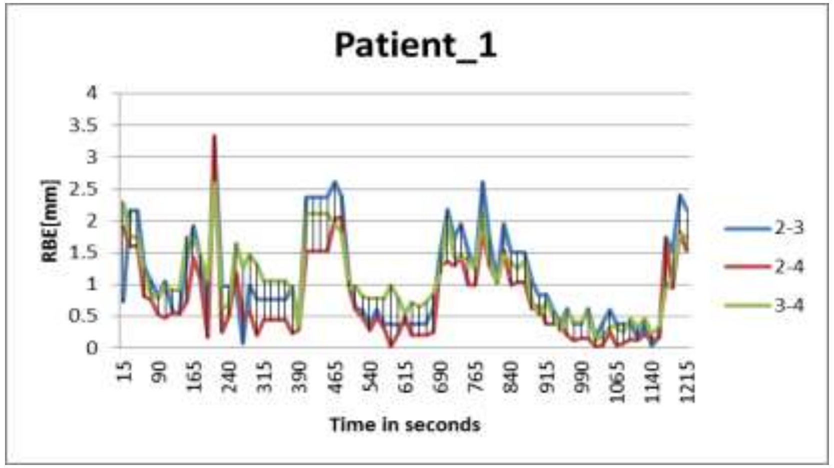


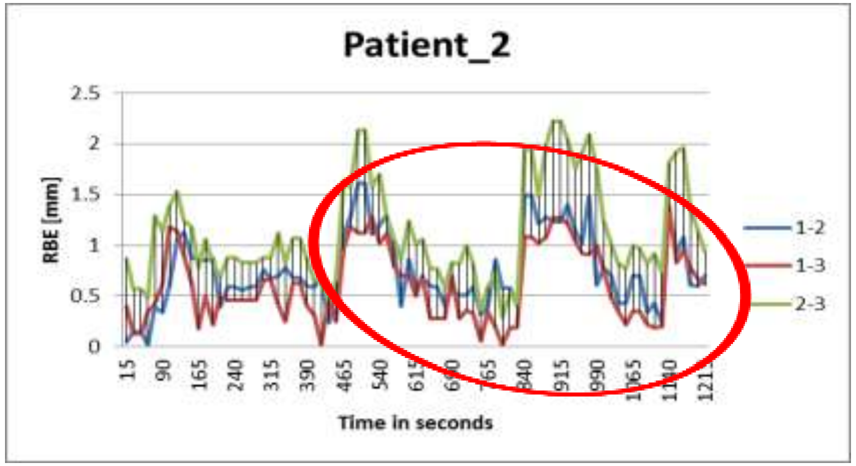
Real Time Motion-Pitch, Roll and Yaw

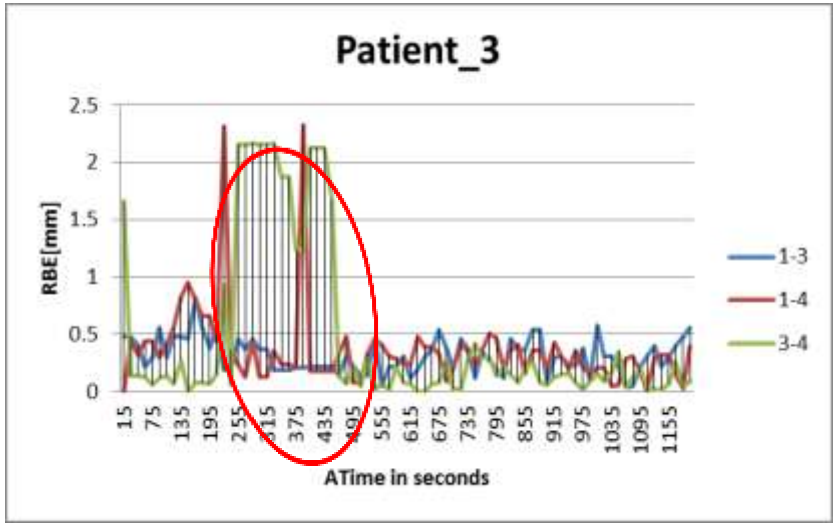


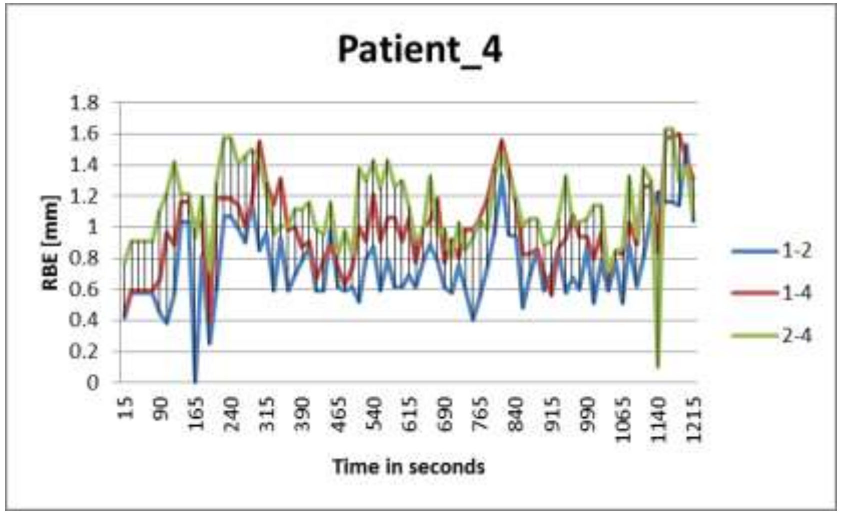


Prostate Deformation



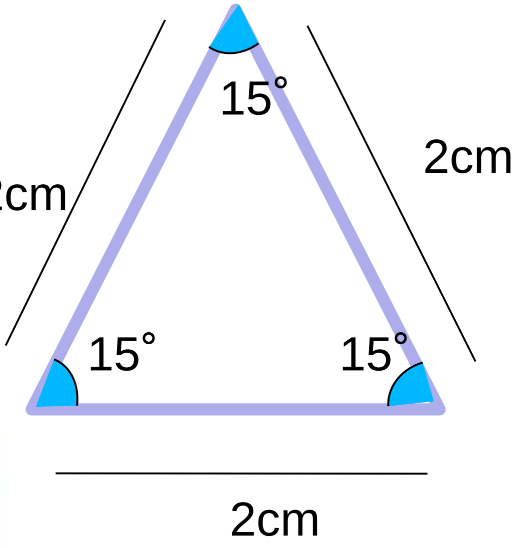


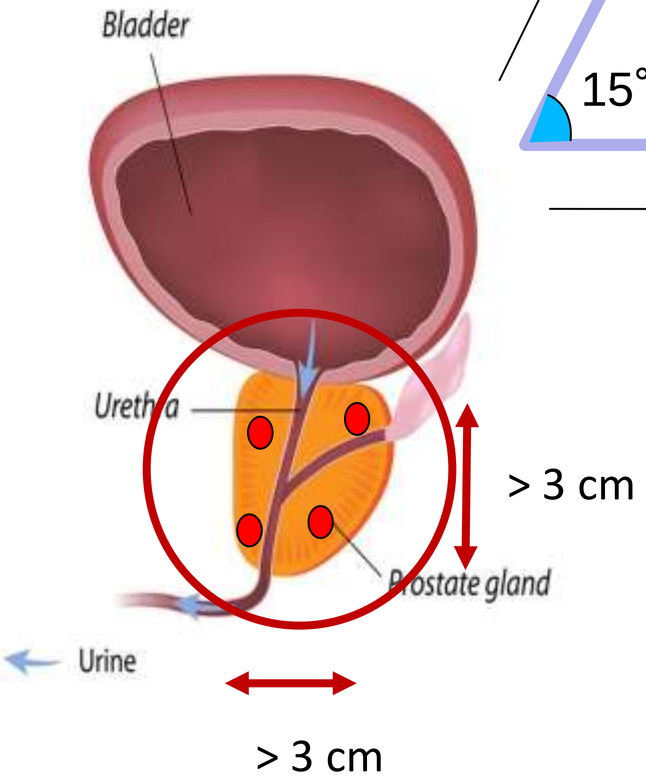




Gupta D et al,2014,ESTRO 2014

Fiducial Image Guidance in all cases for SBRT-Prostate Cancer





- Fiducial Alerts!!

✓ Follow protocol

✓ Spacing: case selection/ image guidance

✓ Antibiotic cover (UTI)

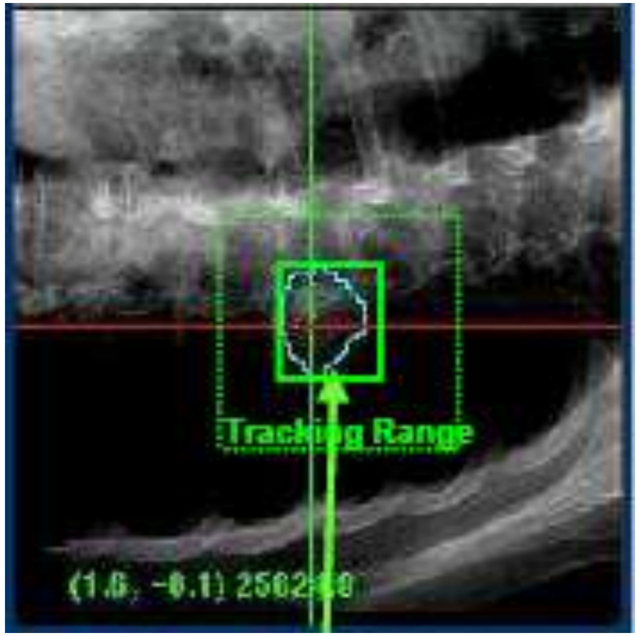
✓ Migration

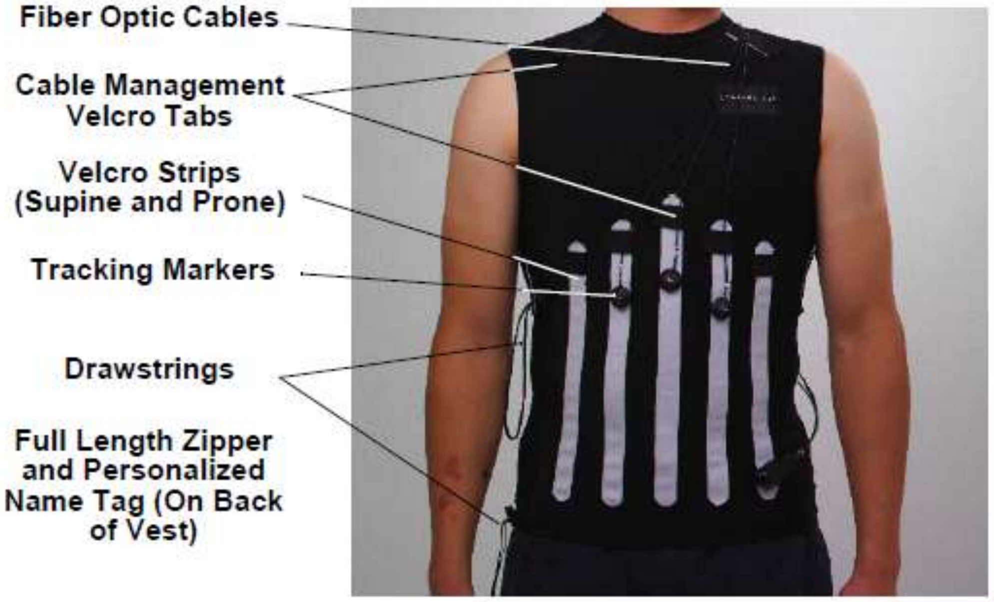
✓ Proper positioning and imaging

X-Sight Spine imaging & correction

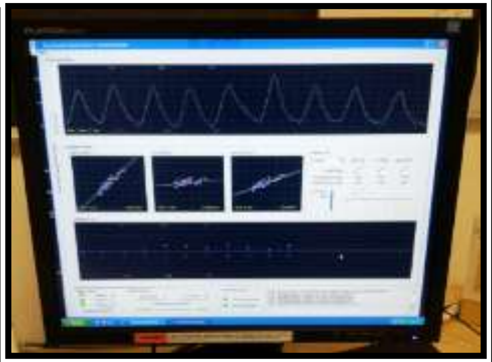
Tracking is performed by moving the matching window throughout a user-defined search area (Tracking range)

The X-Sight Lung Tracking Algorithm locates for an intensity pattern of target in live images that is similar to that in the DRR images



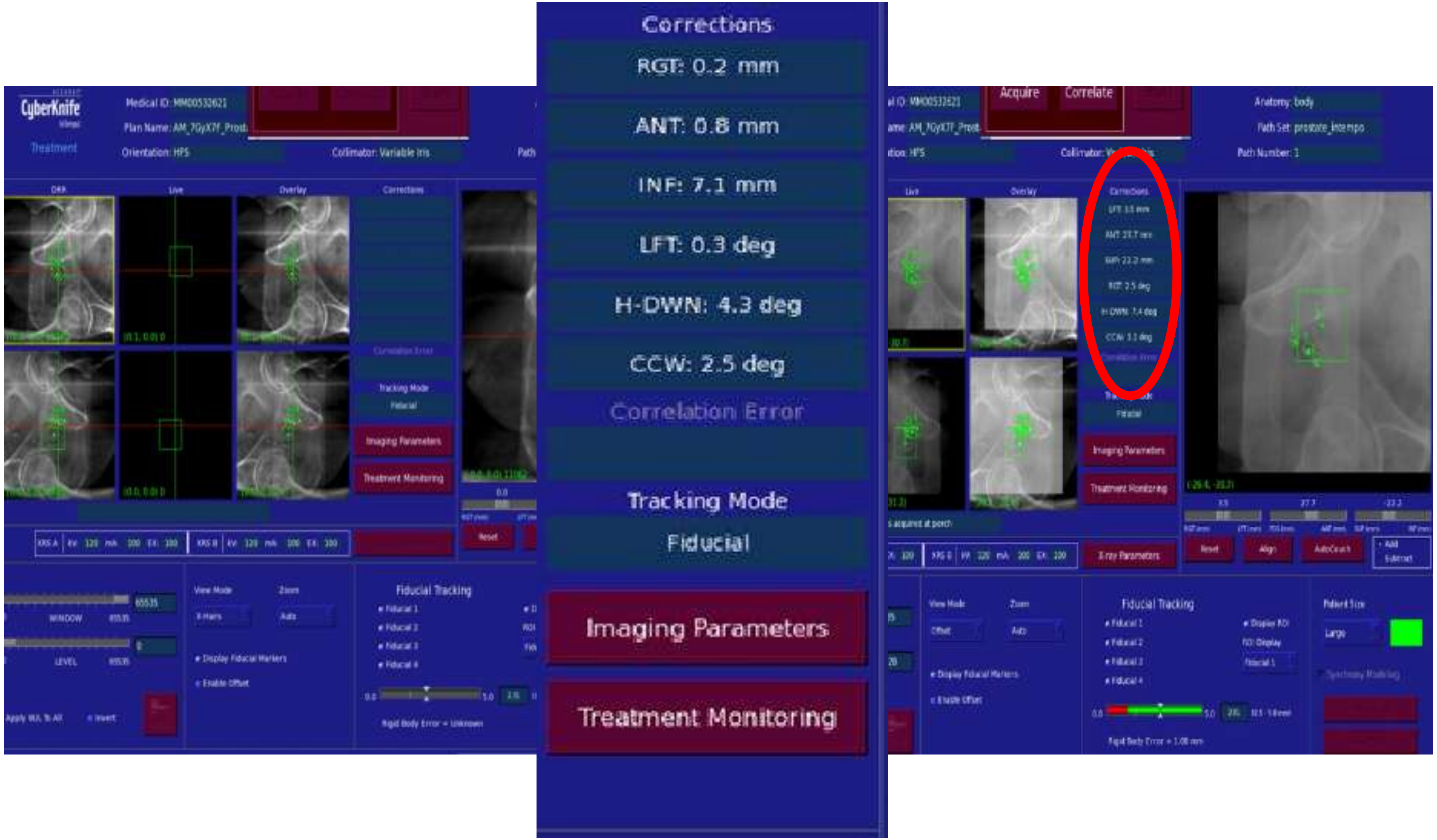


Synchrony Tracking Vest



Both 2- view and 1 view Tracking Systems are used in combination with the X-Sight Spine Tracking System and Synchrony Tracking system

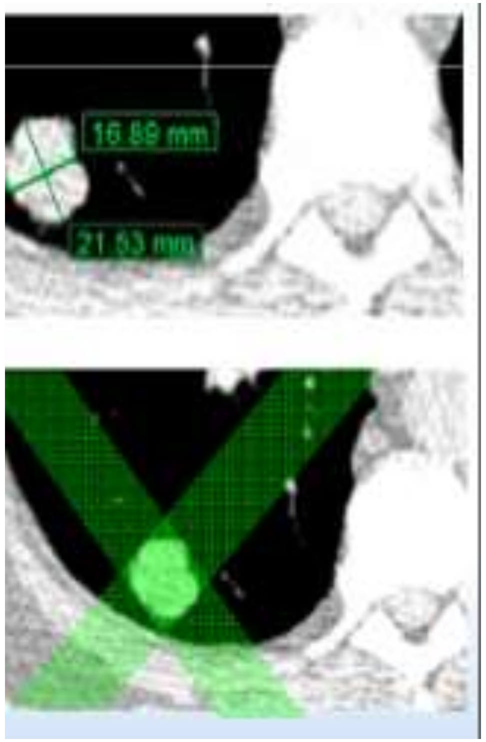
Real time imaging & correction



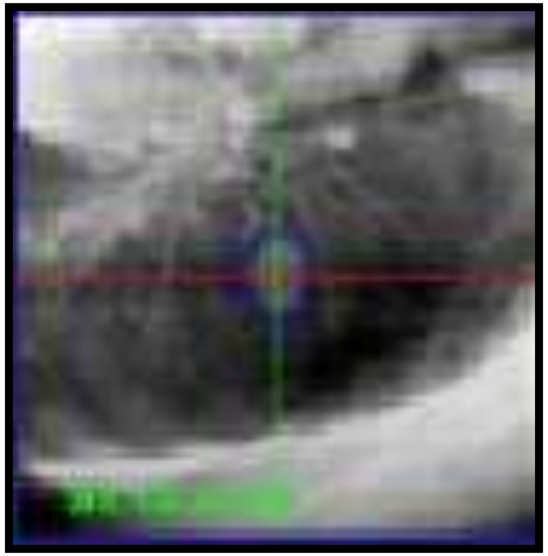
Determining Tracking Modality

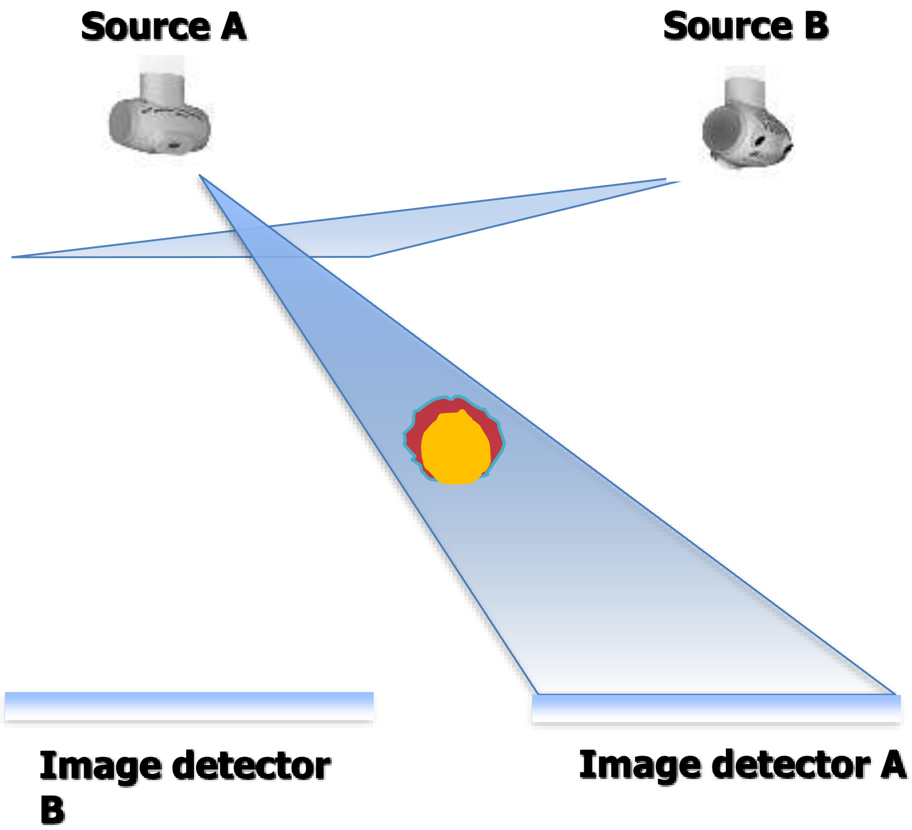
- 2-view Tracking is possible if tumor is more than 15 mm and is visible in both the live images
- 1-View Tracking can be done if tumour is more than 15 mm and is only visible in one of live image or obstructed by bone or any other structure in other live image.
- 0-View Tracking can be done if tumour is not visible in any of two Live images.
- Fiducial Tracking

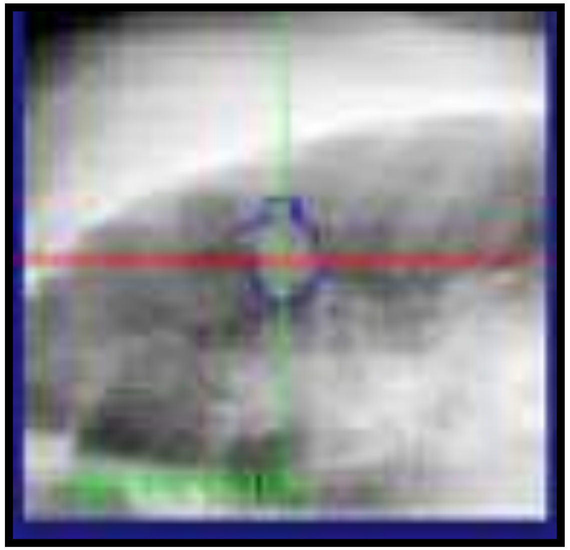
Note- simulator application option assists in determining the appropriate tracking modality for fiducial free tracking.



X-Sight Lung Tracking (2-View)





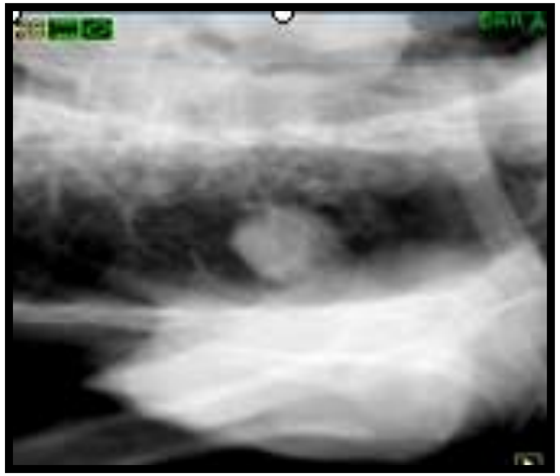


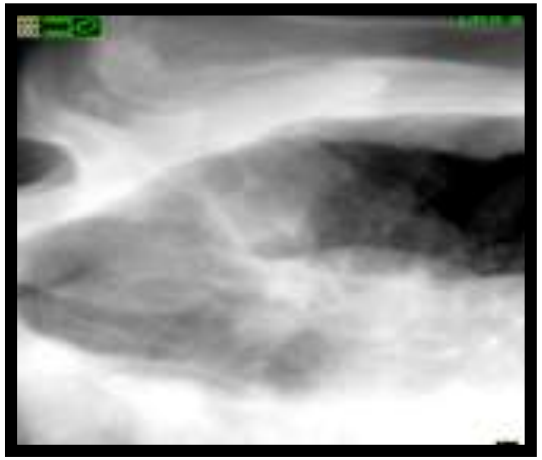
Tumor visible by the targeting software

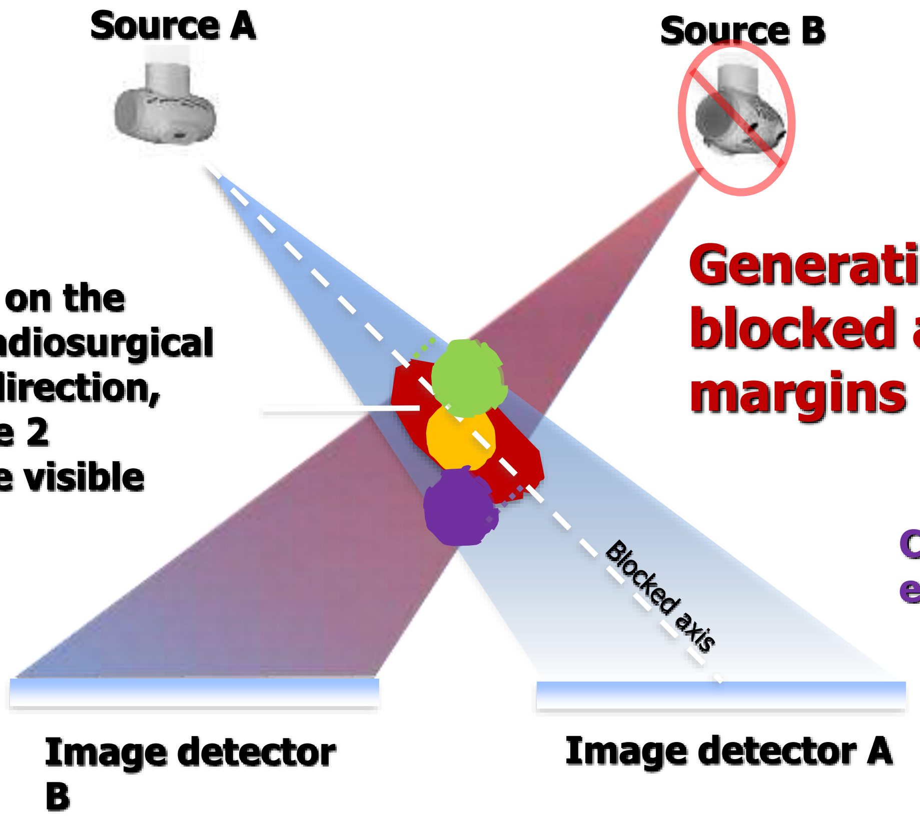
GTV– PTV : Radiosurgical margins (1.5 mm RMS)

Xsight Lung Tracking allow radiosurgical margins in all directions

1-View Tracking







PTV (ITV expansion on the blocked direction, radiosurgical margins in sup/inf direction, always visible by the 2 detectors, and in the visible axis)

Generation of ITV on the blocked axis, radiosurgical margins elsewhere

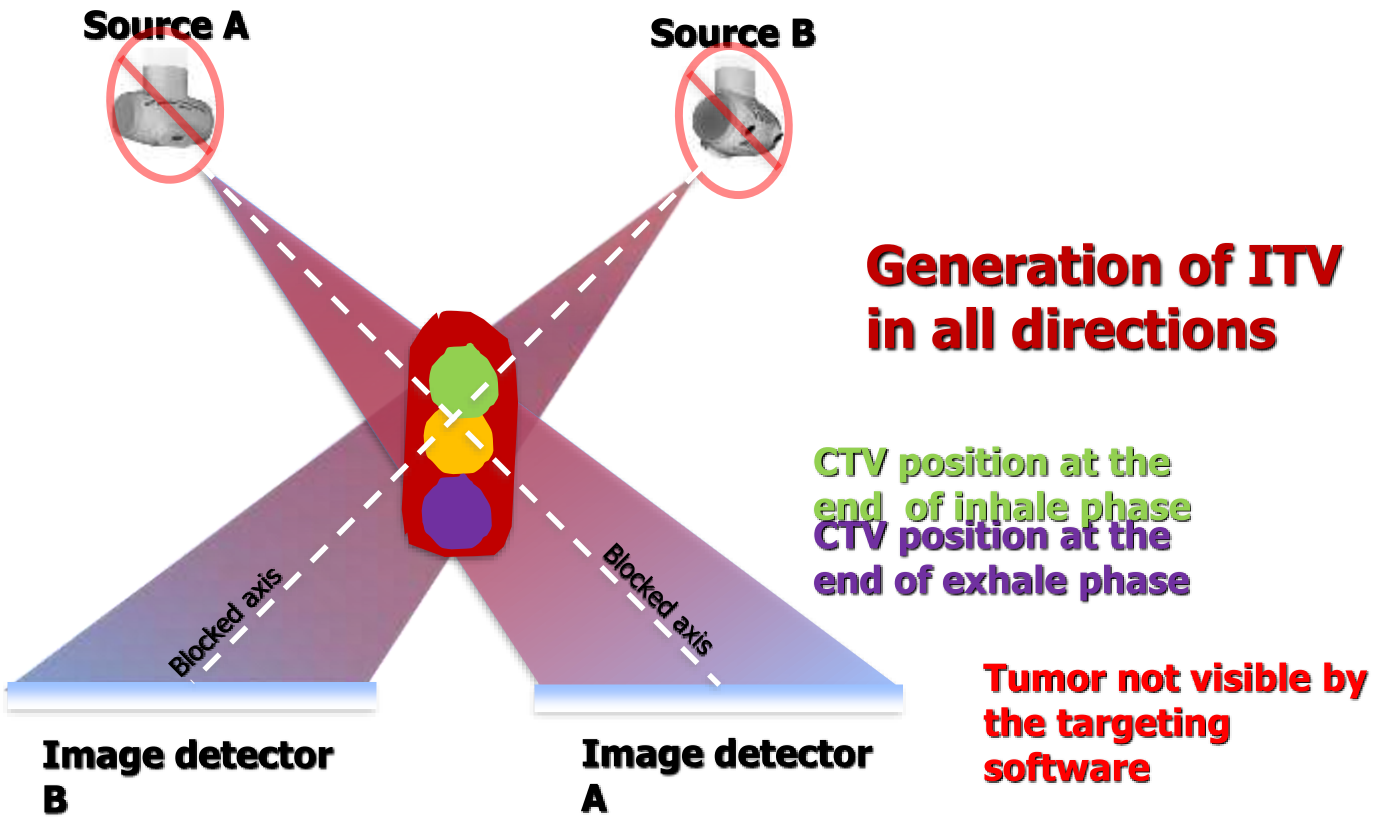
CTV position at the end of exhale phase

Tumor visible by the targeting software

ITV from combining
End Insp and
End expiration
Tumor volume

1 View Tracking allows a Radiosurgical margin in the plane seen by the camera. ITV expansion will be performed for the non- visible axis

0-View Tracking- Spine Tracking



Xsight® Spine Tracking : ITV expansion in all directions

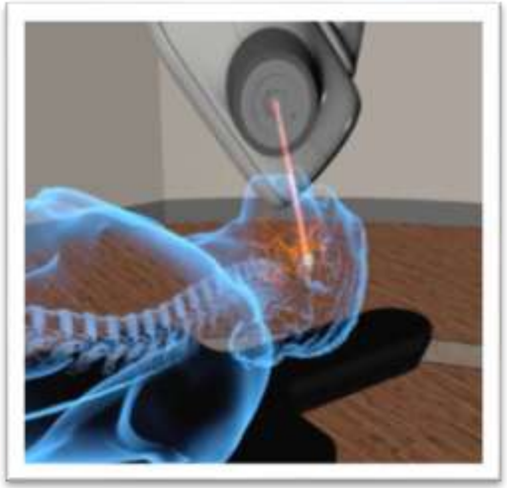
Gamma Knife

Novalis

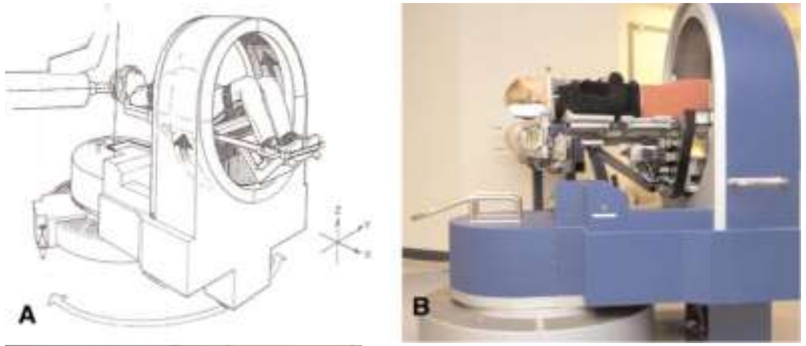
Edge RadioSurgery

Elekta-Axesse

Cyberknife Robotic Radio Surgery-Fixed & Iris



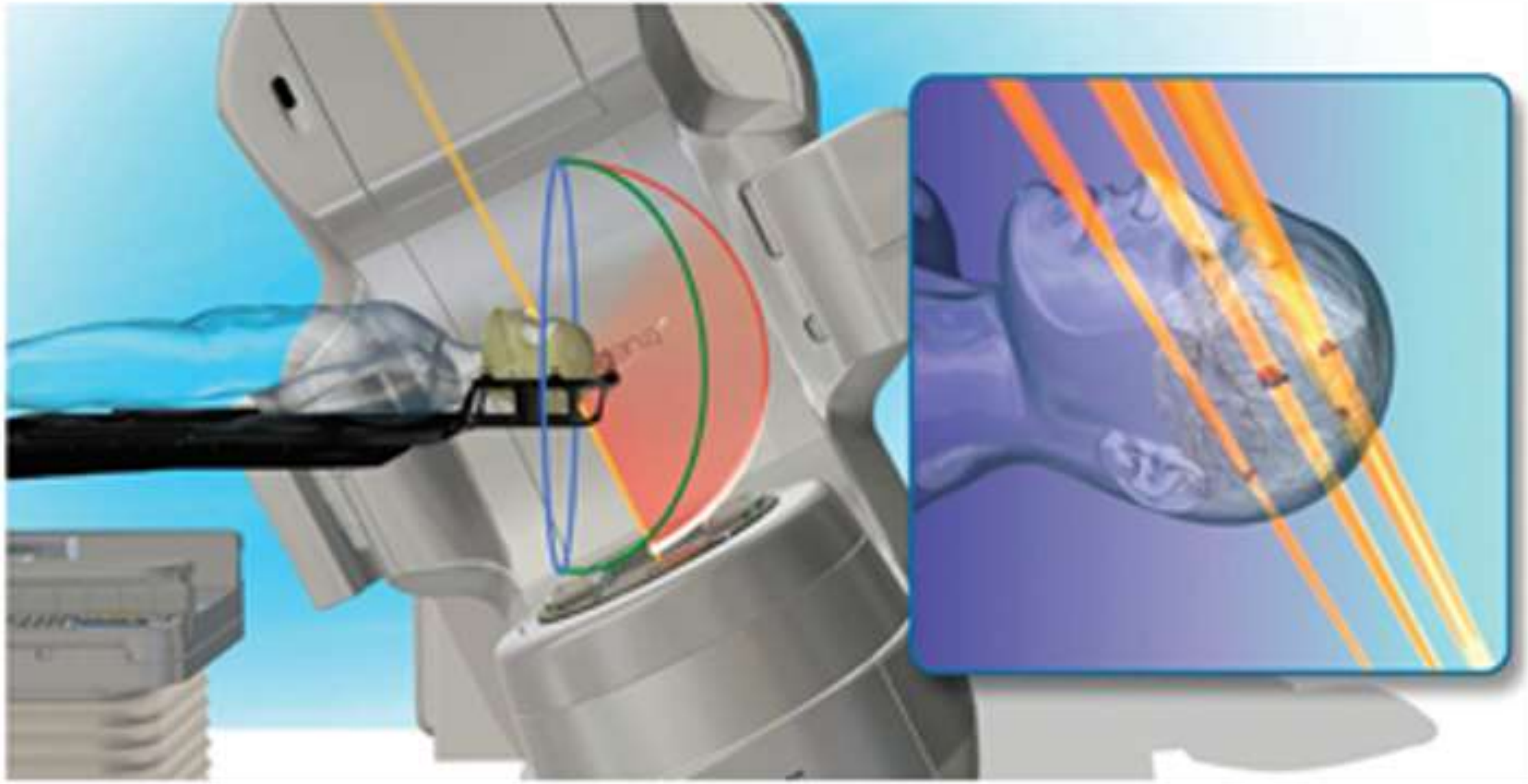
Proton Therapy System



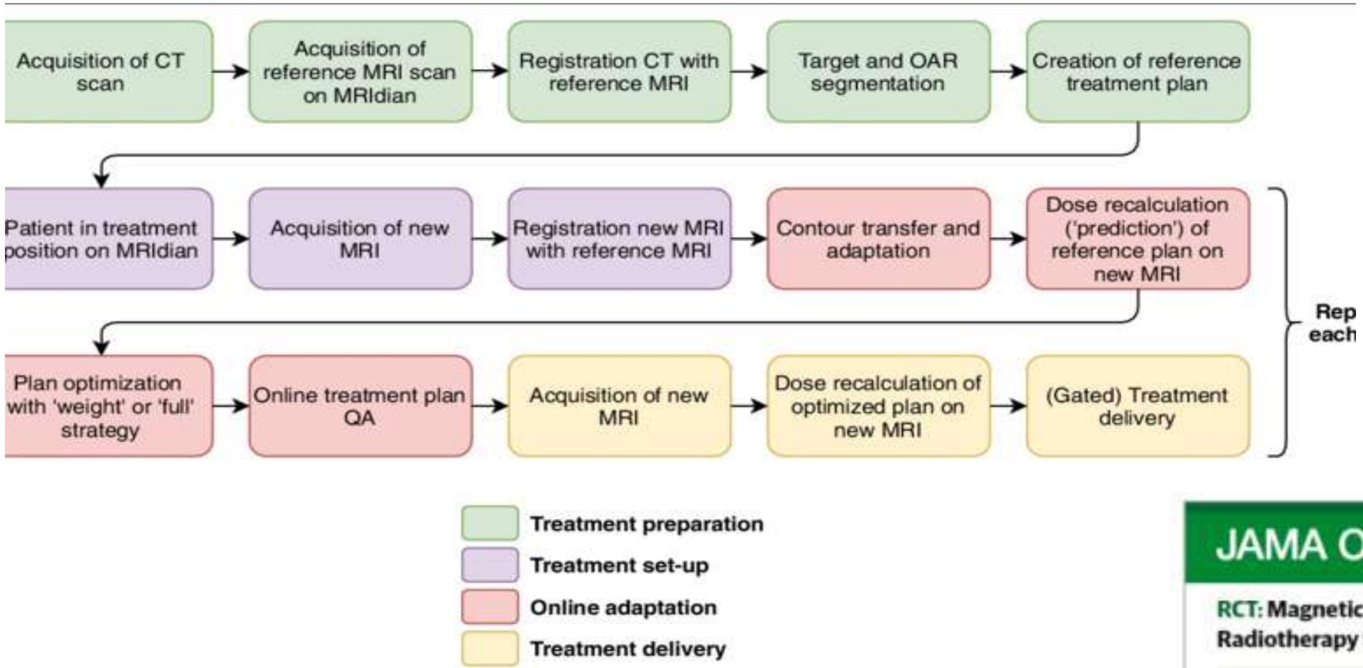
In the early 1960s, researchers from Mass General and Massachusetts Eye and Ear began working with the cyclotron staff to treat patients using proton beam therapy. Its first application was for benign tumors of the pituitary gland.

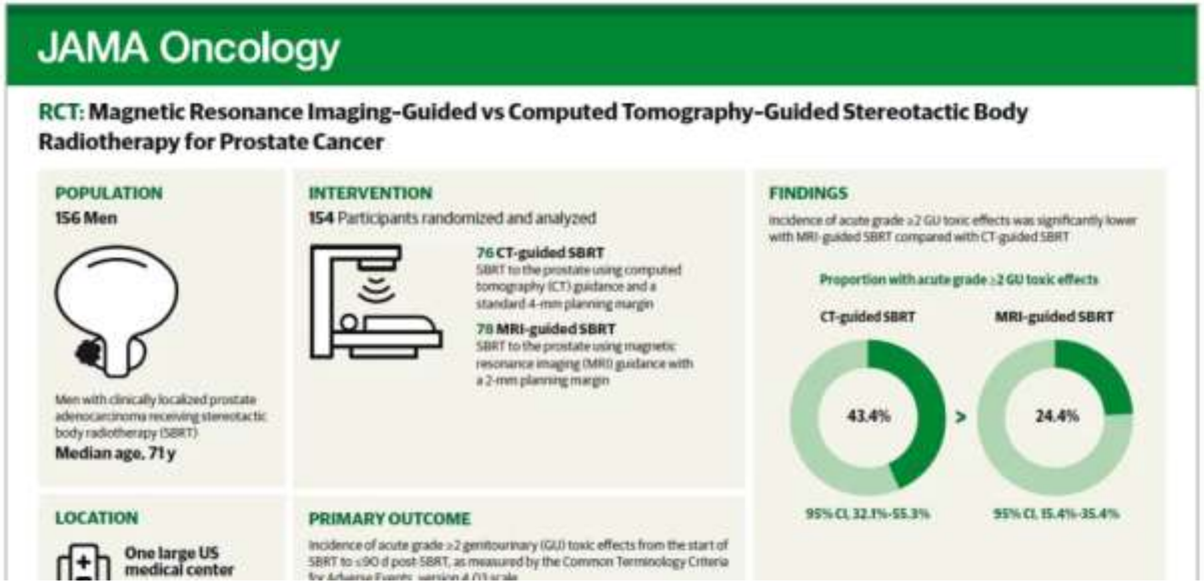
ZAP-X Gyroscopic Radiosurgery platform.
The ZAP-X linear accelerator (LINAC) is an image-guided radiosurgery system that self-shields radiation as a way to allow vault-free radiation delivery.

HYPERARC SRS System for multiple Brain Metastases-CBCT Guided

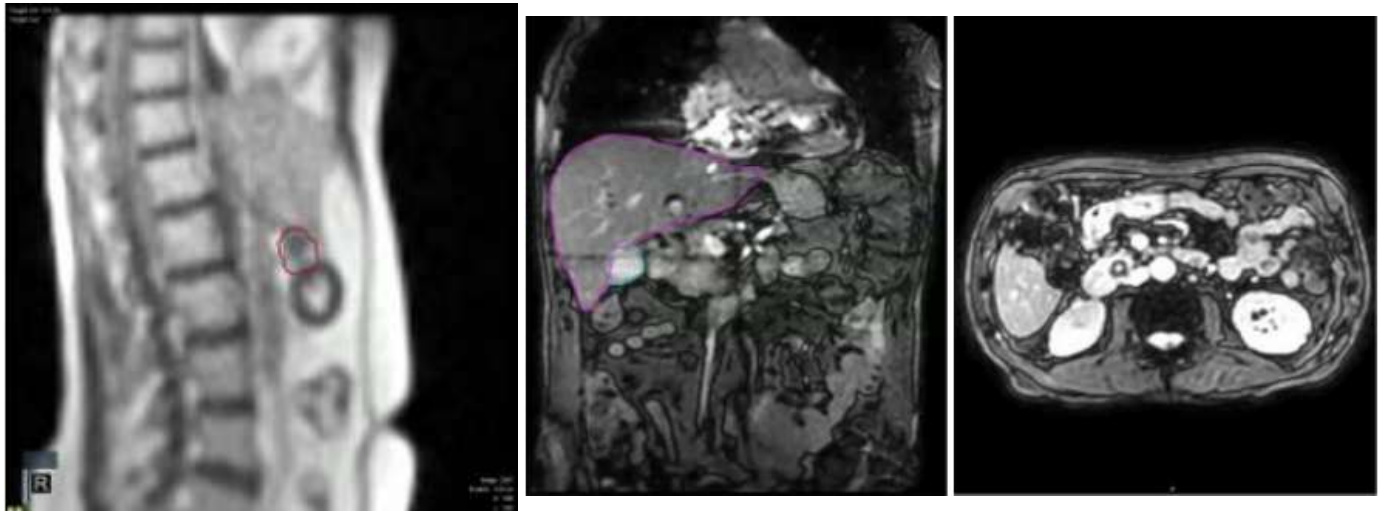


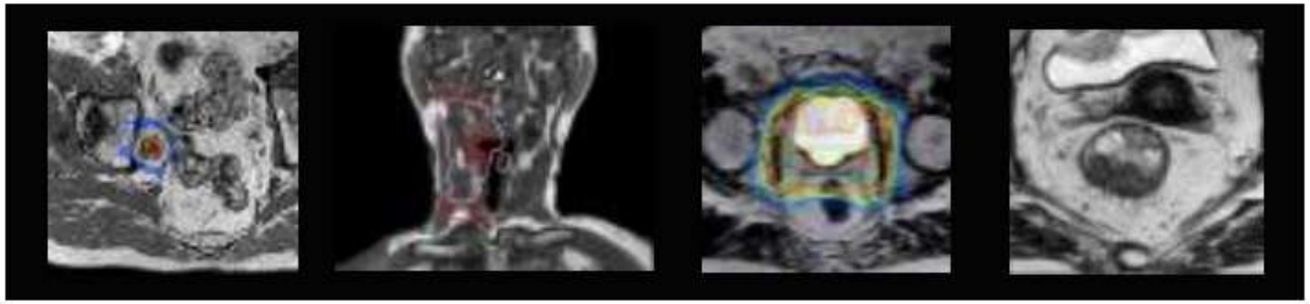
MR-Guided SBRT





MR Image Guided SBRT

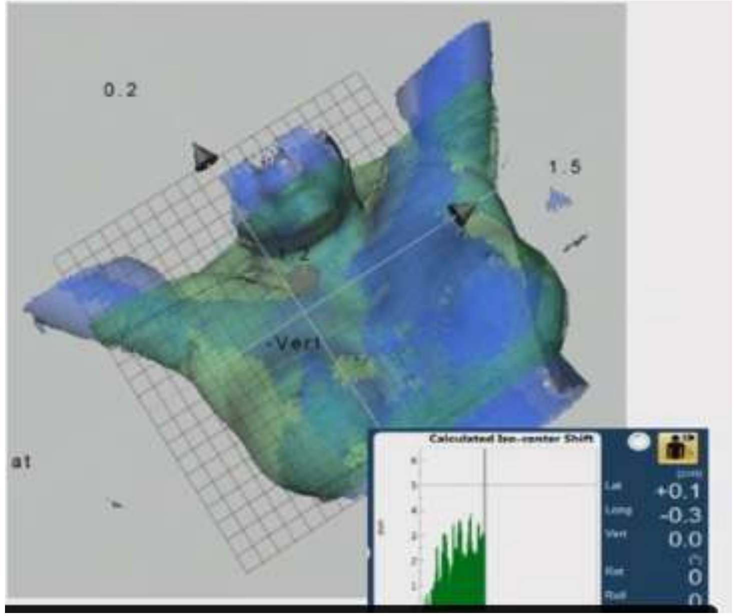




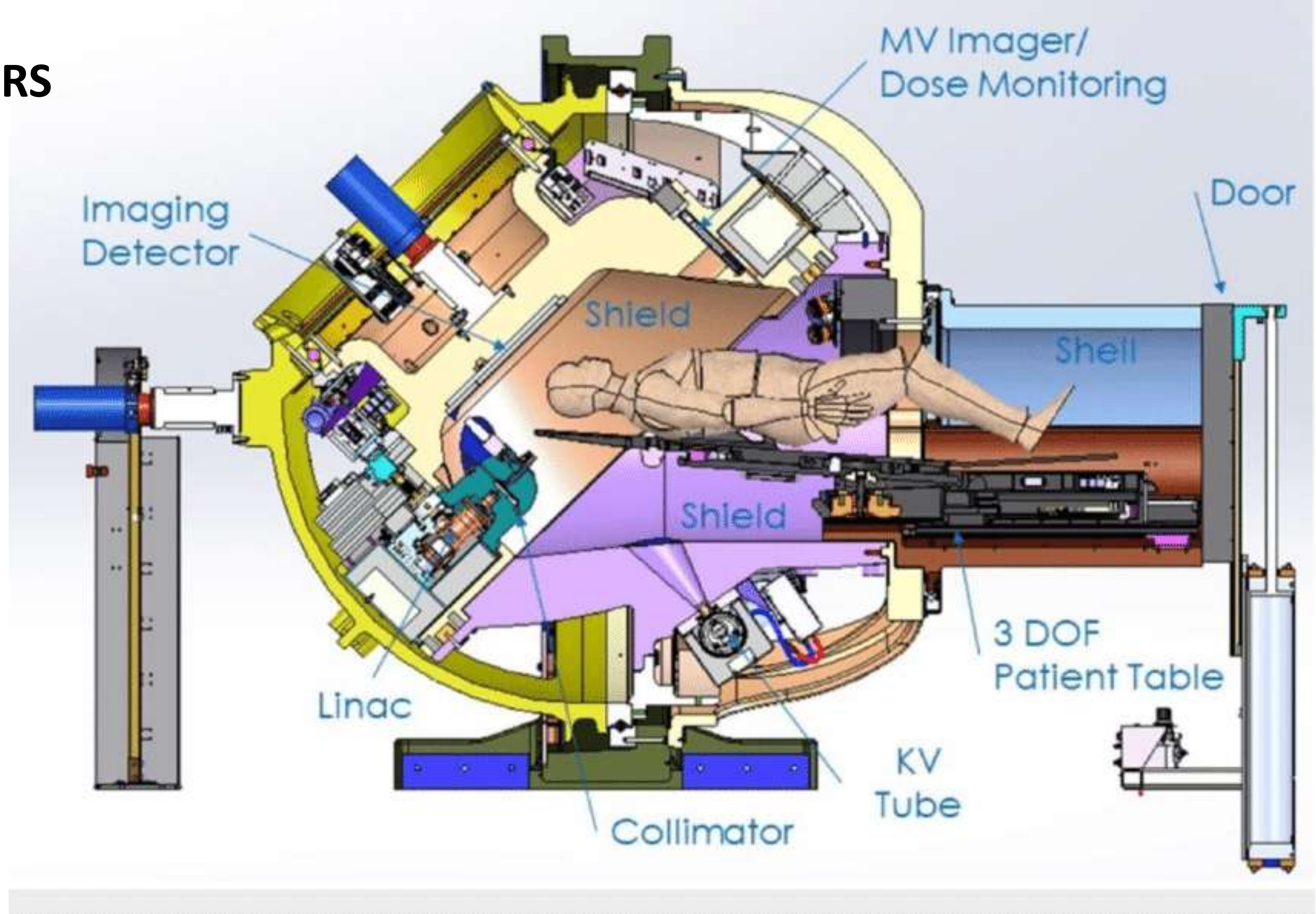
- Better image quality (Soft tissue contrast)
- Real time imaging
- Online adaptive planning
- No imaging dose

Surface Guided SBRT

- SGRT improves patient setup accuracy
- Reduce patient setup time
- Non-Ionizing and non-invasive technique
- Intrafractional patient monitoring
- Monitors both patient motion and breathing movement
- Minimize reimaging and reduce imaging dose



ZAP SRS


MV Imager/
Dose Monitoring
Door
Imaging
Detector
Shield
Shell
Shield
3 DOF
Patient Table
Linac
KV
Tube
Collimator

Imaging dose *not* incorporated into treatment plan

Imaging dose *is* incorporated into treatment plan

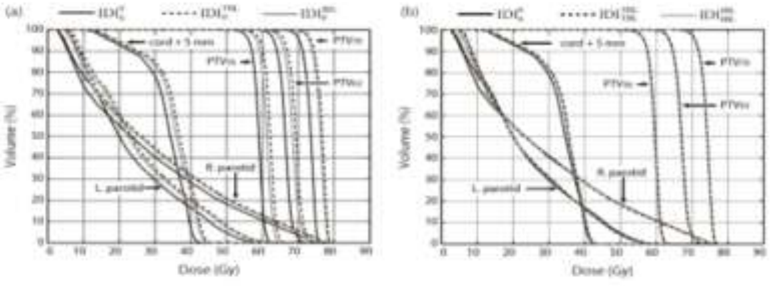
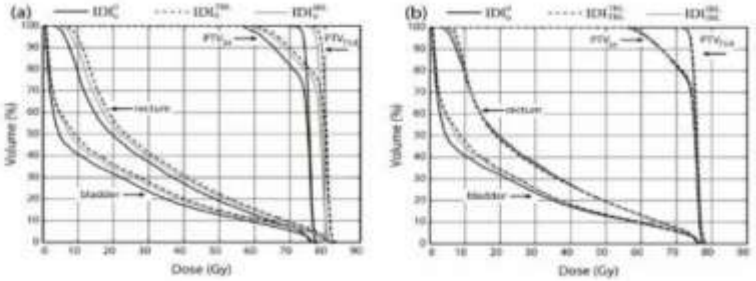


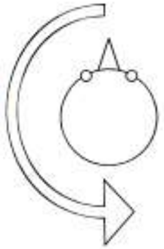
Fig. 10. DVHs for the head and neck case.

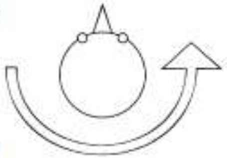
Imaging dose *not* incorporated into treatment plan

Imaging dose *is* incorporated into treatment plan



- Head scan
  - XVI
    - 36.1 mAs
    - Image acquisition begins anterior, rotates around left lateral, and finishes posterior
      - Many superficial organs on anterior side of head
  - OBI
    - 145 mAs
    - Image acquisition moves from left to right lateral (or vice-versa) while rotating around posterior side of head





Tissue/organ	Organ doses (mGy) XVI	Organ doses (mGy) OBI
Brain	0.70	3.01
Salivary glands	0.78	2.42
Thyroid	0.05	0.00
Esophagus	0.02	0.01
Lung	0.01	-
Breast	-	-
Liver	-	-
Stomach	-	-
Colon	-	-
Bladder	-	-
Gonads (testes)	-	-
Bone marrow (whole body)	0.07	0.28
Bone marrow (irradiated site)	0.80	3.45
Bone surface (whole body)	0.11	0.47
Bone surface (irradiated site)	0.80	3.45
Skin (whole body)	0.09	0.16
Skin (irradiated site)	1.34	2.39
Remainder organs		
Extrathoracic region	0.60	1.06
Oral mucosa	0.69	1.39
Thymus	0.01	-
Heart	-	-
Spleen	-	-
Adrenals	-	-
Gall bladder	-	-
Kidneys	-	-
Pancreas	-	-
Small intestine	-	-
Prostate	-	-
Other organs		
Lens	1.07	0.59
Effective dose (mSv)	0.04	0.12

- Chest scan
  - XVI
    - 1028.8 mAs
    - 26 cm beam width
      - Irradiates organs far outside of treatment volume (thyroid)
    - HVL = 8.9 mm Al
  - OBI
    - 262 mAs
    - 16 cm beam width
    - HVL = 5.7 mm Al

Tissue/organ	Organ doses (mGy)	
	XVI	OBI
Brain	0.49	0.14
Salivary glands	1.86	0.30
Thyroid	19.24	2.38
Esophagus	13.56	3.23
Lung	14.29	4.31
Breast	16.80	5.34
Liver	6.58	0.97
Stomach	4.68	0.74
Colon	0.40	-
Bladder	0.03	-
Gonads (testes)	-	-
Bone marrow (whole body)	5.14	1.29
Bone marrow (irradiated site)	12.42	3.27
Bone surface (whole body)	2.59	0.63
Bone surface (irradiated site)	12.42	3.27
Skin (whole body)	2.62	1.03
Skin (irradiated site)	14.92	5.85
Remainder organs		
Extrathoracic region	5.21	0.85
Oral mucosa	1.34	0.38
Thymus	14.29	4.83
Heart	13.87	4.50
Spleen	7.17	0.93
Adrenals	3.76	0.65
Gall bladder	1.83	0.14
Kidneys	1.20	0.08
Pancreas	1.21	0.06
Small intestine	0.28	-
Prostate	-	-
Other organs		
Lens	0.52	0.15
Effective dose (msV)	7.15	1.82

- Pelvis scan
  - XVI
    - 1646.1 mAs
    - 12.5 cm beam width
    - HVL = 8.9 mm Al
  - OBI
    - 680 mAs
    - 16 cm beam width
      - More scatter
    - HVL = 6.4 mm Al
      - Lower HVL, higher dose per unit mAs

Tissue/organ	Organ doses (mGy)	
	XVI	OBI
Brain	-	-
Salivary glands	-	-
Thyroid	-	-
Esophagus	-	-
Lung	0.02	0.01
Breast	-	-
Liver	0.19	0.28
Stomach	0.23	0.30
Colon	2.04	3.26
Bladder	15.67	15.30
Gonads (testes)	29.00	34.61
Bone marrow (whole body)	1.05	1.14
Bone marrow (irradiated site)	5.50	5.77
Bone surface (whole body)	1.17	1.14
Bone surface (irradiated site)	5.50	5.77
Skin (whole body)	3.07	3.05
Skin (irradiated site)	27.88	27.77
Remainder organs		
Extrathoracic region	-	-
Oral mucosa	-	-
Thymus	-	-
Heart	0.10	0.08
Spleen	0.20	0.28
Adrenals	0.23	0.34
Gall bladder	0.28	0.52
Kidneys	0.31	0.59
Pancreas	0.33	0.52
Small intestine	1.06	1.72
Prostate	27.63	27.25
Other organs		
Lens	-	-
Effective dose (msV)	3.73	4.34

Acknowledgements-

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Mr Amit Gupta

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Dr Anubhav Khandelwal
Dr Ajay Kapoor
Dr Soumil Gupta
Dr Sonal Krishan
Dr Bosky Jain

Dr Ashok Sen

Thank You for your patience