AN OVERVIEW OF DIFFERENT COMMERCIAL PLATFORMS FOR SRS/SBRT

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SRS/SBRT AND AN OVERVIEW OF DIFFERENT TECHNOLOGIES

- WHAT IS SRS/SBRT?
- SITES TREATED
- RADIOBIOLOGY
- REQUIREMENTS
- PROCESS OF SRS/SBRT AND A BRIEF ON SOME IMPORTANT COMPONENTS
- OVERVIEW OF DIFFERENT PLATFORMS FOR SRS AND SBSRT

What is SRS/SBRT?

Stereotaxy:

- composed of two Greek words ‘stereo’ and ‘taxis’

  stereo= solid and taxis= position.

- it is a procedure in which points with in the 3D solid structure are localized using reference systems.

SRS [Stereotactic Radiosurgery]:

- It is a non surgical specialised type of external beam radiation therapy in which large doses of highly accurate, precise and conformal ionizing radiations are given to ablate a well defined target volume in single procedure.

SBRT[Stereotactic Body Radiotherapy:

- An external beam radiotherapy method that very precisely delivers a high dose radiation to a extracranial target in a course of 1-5 fractions (1 to few).

Advantages of SRS/SBRT:

- Facilitates high dose delivery to a small target volume in lesser fractions.
- Acceptable toxicities to surrounding normal tissues due to rapid dose fall off.
- Higher accuracy.
- Faster treatment time.
- Patient comfort.

All these factors collectively lead to better clinical outcome.

SITES:

INTRACRANIAL

- AVM S
- Acoustic neuromas
- Meningiomas
- Pituitary Adenomas
- Vagal schwannomas
- Brain mets
- GBM/Astrocytoma

EXTRACRANIAL

- Head and neck
- Lung
- Pancreas
- Kidneys
- Adrenal gland
- Liver
- Prostate
- spine

RADIOBIOLOGY:

Potential high dose mechanisms of cell killing other than DNA damage.

1. **Radiation induced vascular damage:**

- Tumour micro vasculature is tortuous, irregular and thin walled unlike normal vasculature.
- High dose >10Gy (per fraction), leads to destruction of tumour vasculature.
- Proposed as reason for superior tumour control.

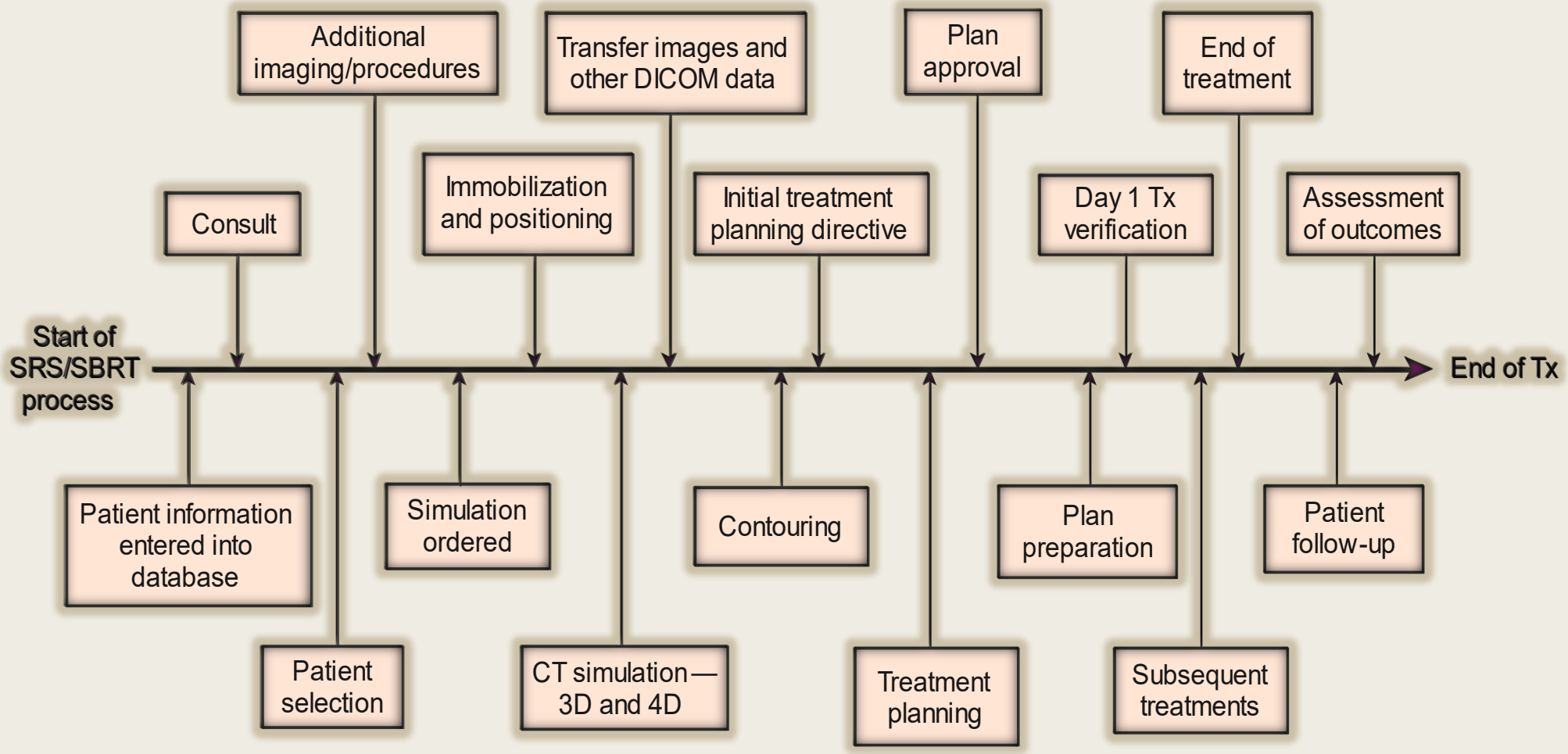
2. **Immunogenic effects:**

- high dose per fraction promote both local and systemic inflammation and may potentiate effects of immunotherapy.
- The abscopal effect may prevent subclinical metastases.

3. **Bath and shower effect in normal tissues:**

- Surrounding a high dose length of cord(the shower) by a longer length low dose bath reduces the tolerance dose of high dose region.

Process of SRS / SBRT:



Requirements for SRS/SBRT:

- ✓ 3D imaging and localisation technique.
- ✓ Integration of imaging systems.
- ✓ 4D imaging techniques for moving targets such as lung and liver.
- ✓ Motion management techniques during the treatments.
- ✓ Immobilisation systems
- ✓ Treatment Planning systems for accurate high conformal dose distribution with sharp dose gradient.
- ✓ Special calculation algorithms.
- ✓ Platforms suitable for SBRT/SRS.
- ✓ Image guidance technology and techniques for verification during treatment.

Some important components of process of SRS/SBRT:

- Immobilisation:

  1.Intracranial

  2.Extracranial

- Motion management
- Imaging techniques
- Treatment planning

Immobilisation:

- Improved localisation of target structures permits smaller treatment planning margins.
- Smaller targets allows higher doses and safety of oars.
- Effective immobilisation is critical in minimizing intrafraction motion of patients which can be catastrophic in high dose delivery.
- For this purpose different frames and moulds are used with reference scales and fiducials to generate stereotactic coordinates for target localisation to permit noncoplanar treatments.

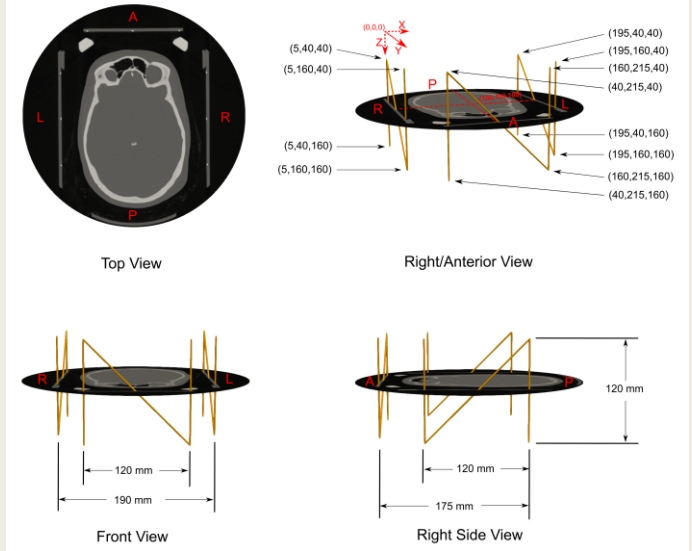
Intracranial Immobilisation:

- Can be of two types : invasive and non invasive fixation.
- Both are capable of SRS up to 1mm accuracy.
- Though invasive rigid frames provide most accurate localisation, it requires entire process od immobilisation, scanning , planning and treating the patient to be completed in a single day.
- Non invasive ,relocatable frames provide near equivalent accuracy and also allow the planning process to be done over several days.

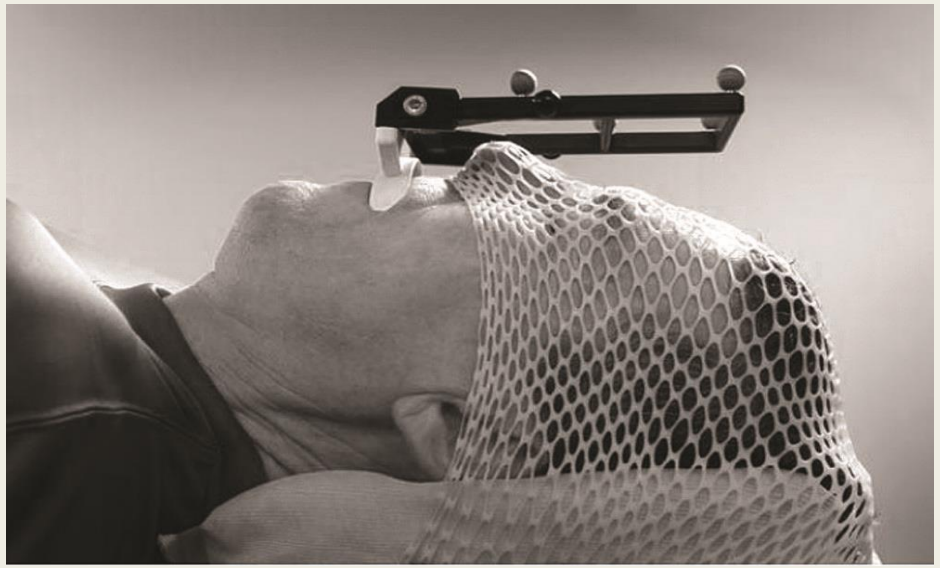
Leksell frame:

- One of the earliest and still used in Gamma knife SRS.
- Attached to pts skull with screws.
- Has stereotactic coordinates systems.
- Origin – patient's right, posterior, superior corner.
- Frame centre- (100,100,100). No negative numbers
- A special helmet to measure depths at several points and to develop a model of pts skull and later to verify frame shift.
- Fiducial box attached to the frame and patient is imaged.

Leksell stereotactic frame

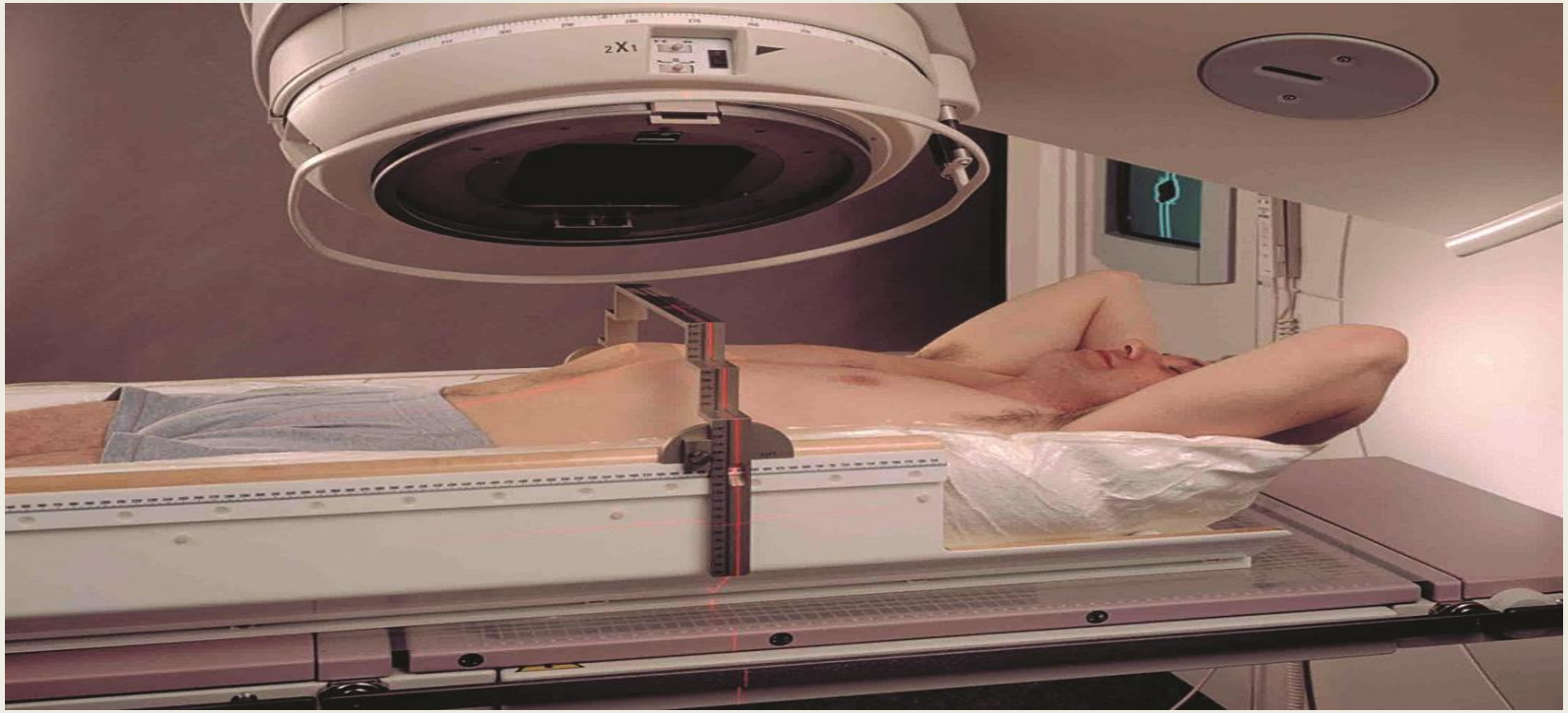


- Recent Gamma knife-Icon used thermoplastic head frame with fiducial markers on reference tools and one on patient’s nose.
- Linac based systems though initially used invasive frames, now non invasive thermoplastic head frames with bite block are being used .
- Thermoplastic mould coupled with image guidance yields accuracy close to rigid invasive frame.

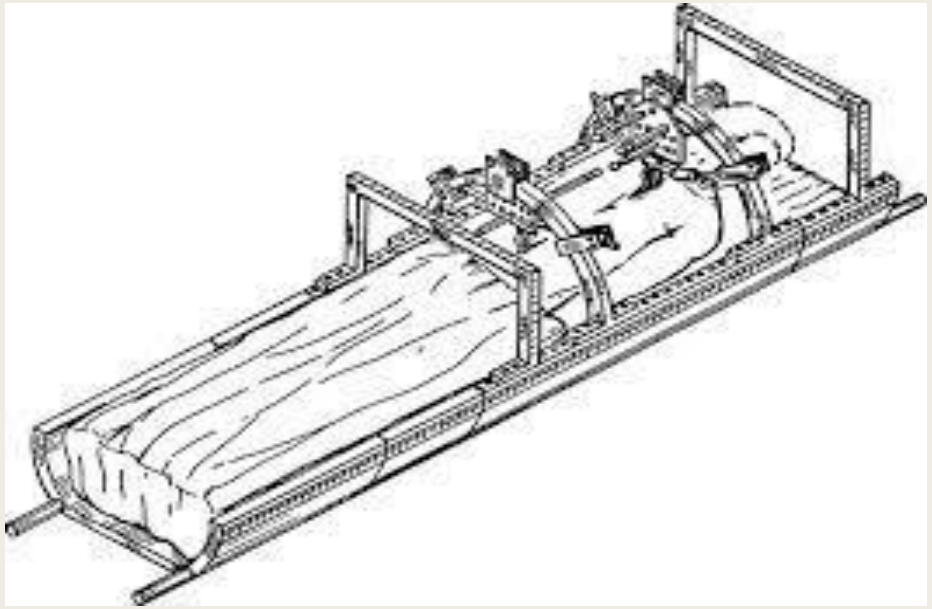


Extracranial immobilisation:

- Due to non rigid anatomy outside cranium, normal requirement of immobilisation pounded by the need to limit internal motion (intra and intertreatment).
- Thus immobilisation coupled with IGRT is an absolute criteria for SBRT.
  - **Elekta body frame:** adopted linear reference scales ,fiducials and abdominal compression plate.



- **Invasive body frame by Hamilton and Lulu** which is fixed to spinous processes with patient in prone position.



- **Elekta body fix frame:** uses double vacuum and polystyrene sphere.
- Body cushion is deflated to hold pt in the frame by uniform pressure

Motion management :

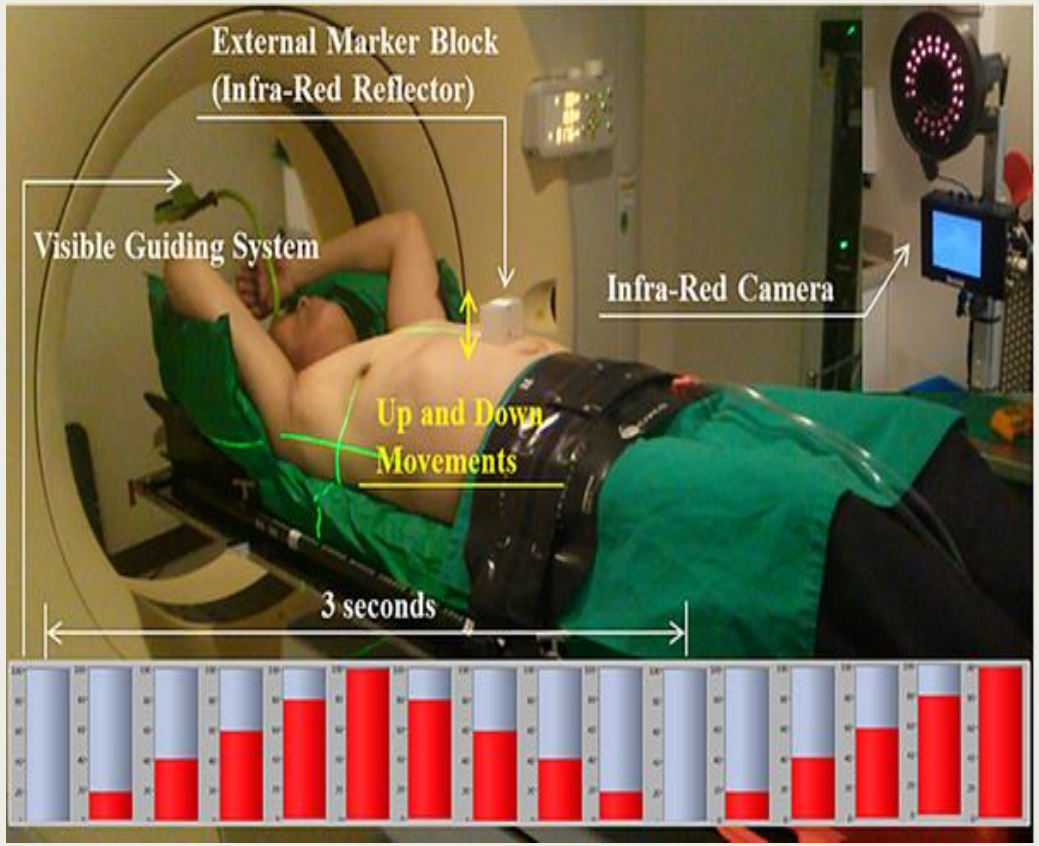
- Large margins as in conventional RT (1.5 -2 cm) may greatly increase toxicities.
- To prevent that methods to reduce movement due to respiration have been incorporated in SBRT.
- First SBRT frame had a belt which reduced diaphragm movement (1.5/2 cm to 0.5 /1 cm).
- Elekta incorporated compression plate connected to arch.
- Arch reduced clearance .
- Pressure plates deforms organs and causes discomfort to patient.

- Body pro lock : Includes a pneumatic pressure belt is fixed and inflated.
  Initially when pressure is applied, abdominal muscles contract momentarily later with time relaxes and pressure changes.
  A guage is attached to check decrease in pressure and hault the treatment.

- **Breath hold technique:**
  Requires patient to hold breath for 15 to 20 seconds.
  Can be held either in inspiration or expiration phase.
  Inspiratory breath hold allows longer duration.
  Less tissue volume can be treated while treating lung carcinoma. Can be carried out by two methods.
  1.Spirometry based active breathing coordinator: incorporated by Elekta systems. Nose is plugged.
  mouthpiece attached to spirometer which connects to a computer.
  Valves closed automatically after threshold is reached. Patient can
  control valves with a switch.

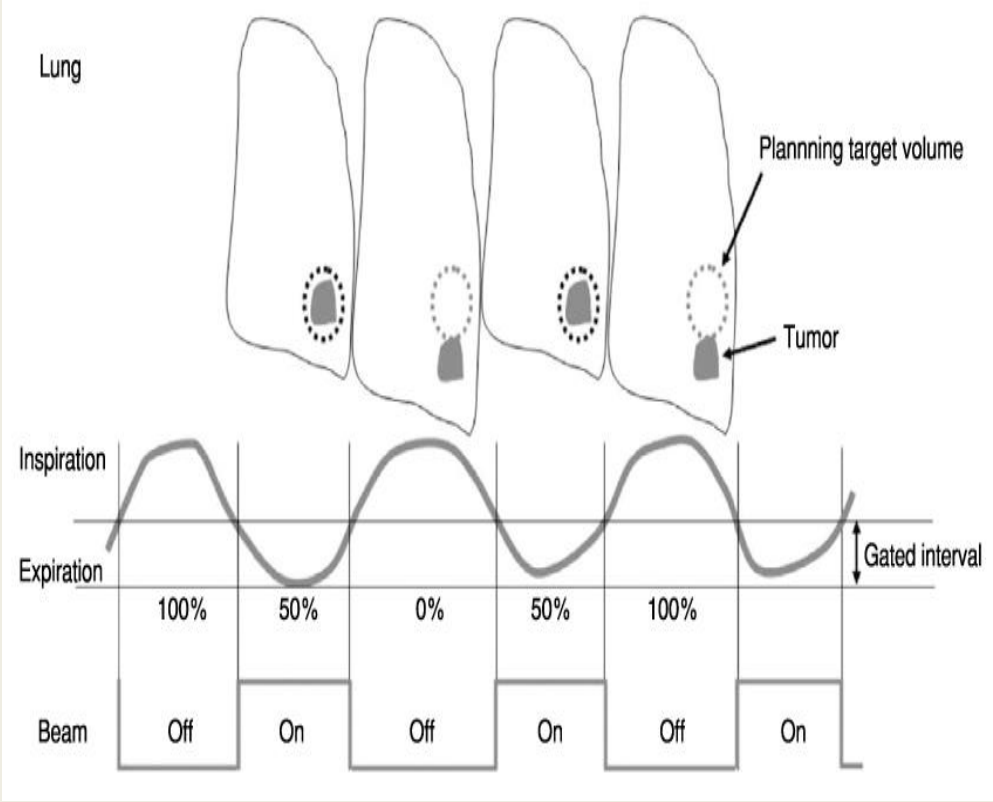
2. Real time position management –video based: incorporated by Varian systems.

- A infrared marker box is placed on xiphoid and patient is asked to breath .
- When the threshold is reached patient is assisted to voluntarily hold his breath.
- RPM camera starts recording and the software holds the beam delivery if motion exceeds the set range.



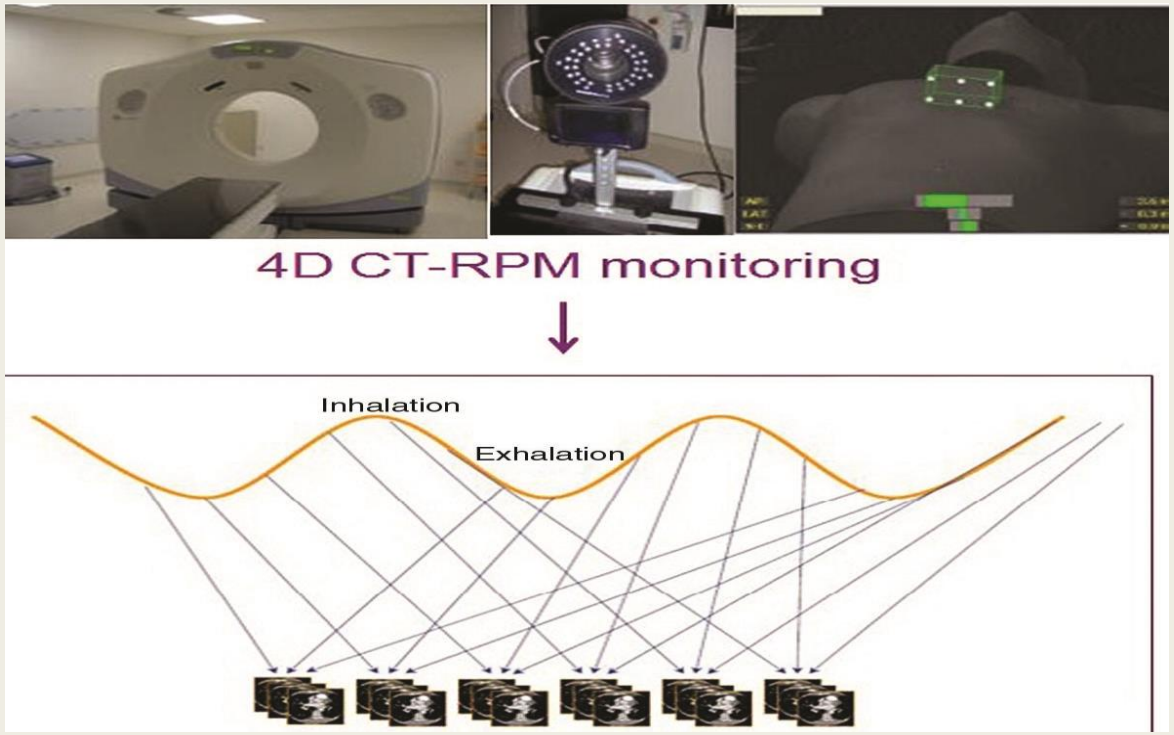
3.Gated treatment:

- Useful when planned to treat only a fraction in breathing cycles.
- Usually a fraction in which motion is minimal.
- Doesn’t require breath holding.
- Beam delivery around 50% of breathing cycle around end exhalation.



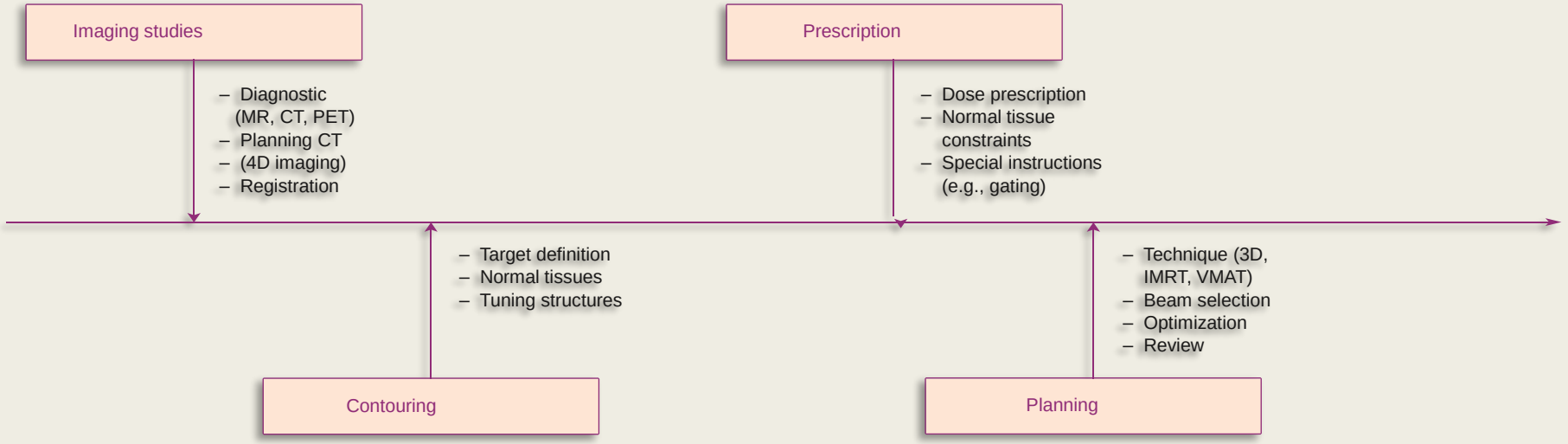
- **Imaging techniques:**
  Imaging should be of high resolution and quality for greater accuracy in planning.
  Slice thickness should be <3mm .
  Extent of scan should be 5-10 cm above and beyond target volume.
  15cm if non planar.

- 3D CT/MRI/PET gives high motion artefacts in a mobile organ.
- 4DCT/MRI/PET is adopted to reduce motion artefacts.
- Has cine mode which scans each section along the long axis for a period slightly longer than 1 breath cycle.
- Multiple images of same section tagged with respiratory signals with RPM system.
- Retrospective SORTING of each image in respective bins and compiling a full 4D image.

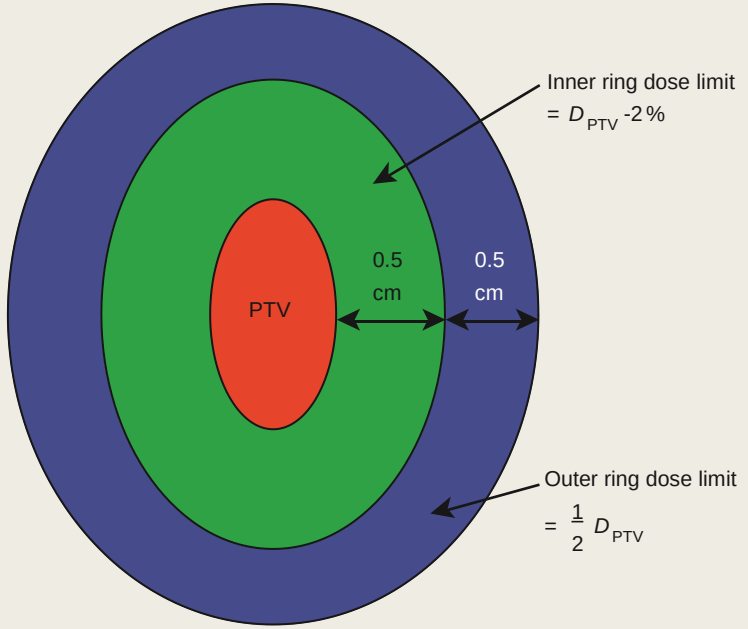


Sorting CT images to generate a 4D CT. Cine CT images are acquired and synchronized to breathing signal. Retrospective sorting generates full CT images at each phase of the breathing cycle.

Treatment planning:



- **Tuning structures:**
- To achieve dose conformity to small target volume and dose gradient surrounding it special ring structures are often used.
- These are called as tuning structures used in planning to promote conformity and evaluate it after plan has been completed



OVERVIEW OF DIFFERENT PLATFORMS FOR SRS/SBRT

Ideal characteristics of a desired system:

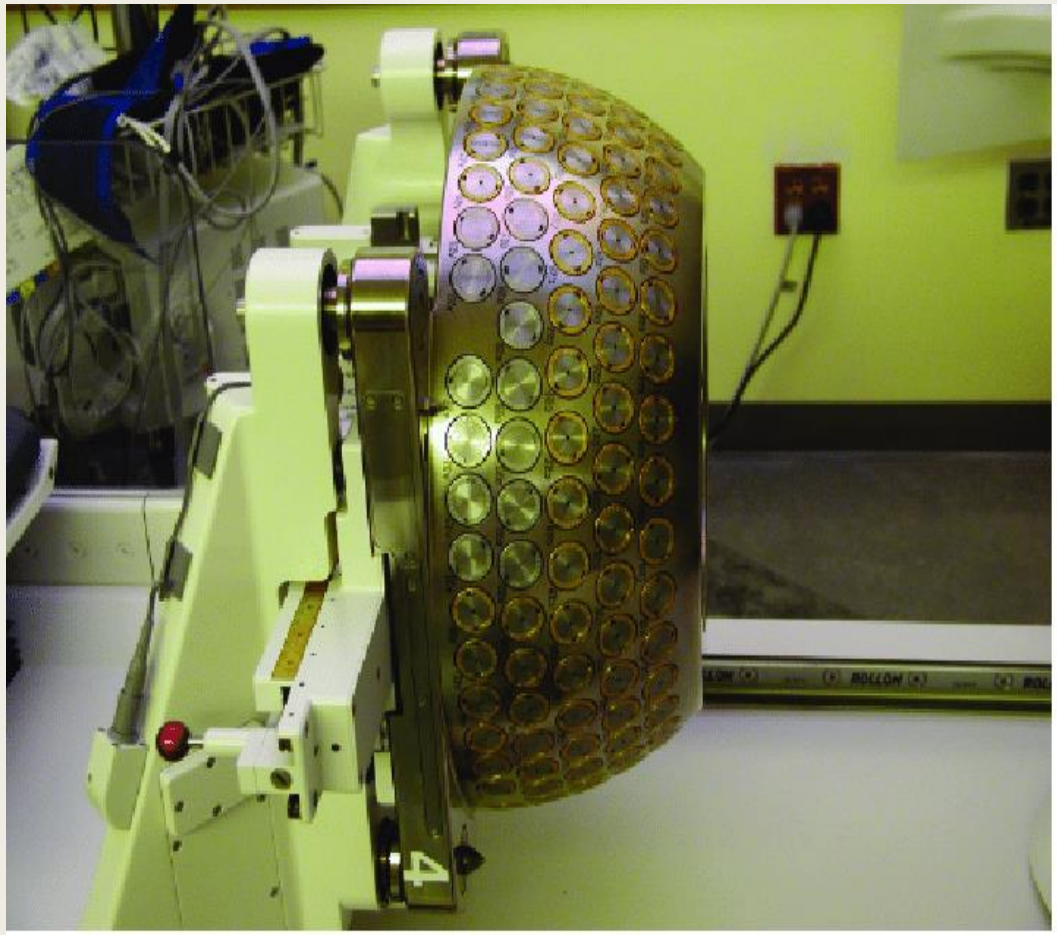
- High dose rate to minimise the treatment time.
- Sharp dose fall of to allow high dose delivery to target without compromising normal tissues.
- High mechanical accuracy.
- On board 3D and localising hardware and software.
- Ongoing monitoring to adjust for patient movements.
- Stability of radiation output with gantry rotation, collimator movement and dose rate variation.

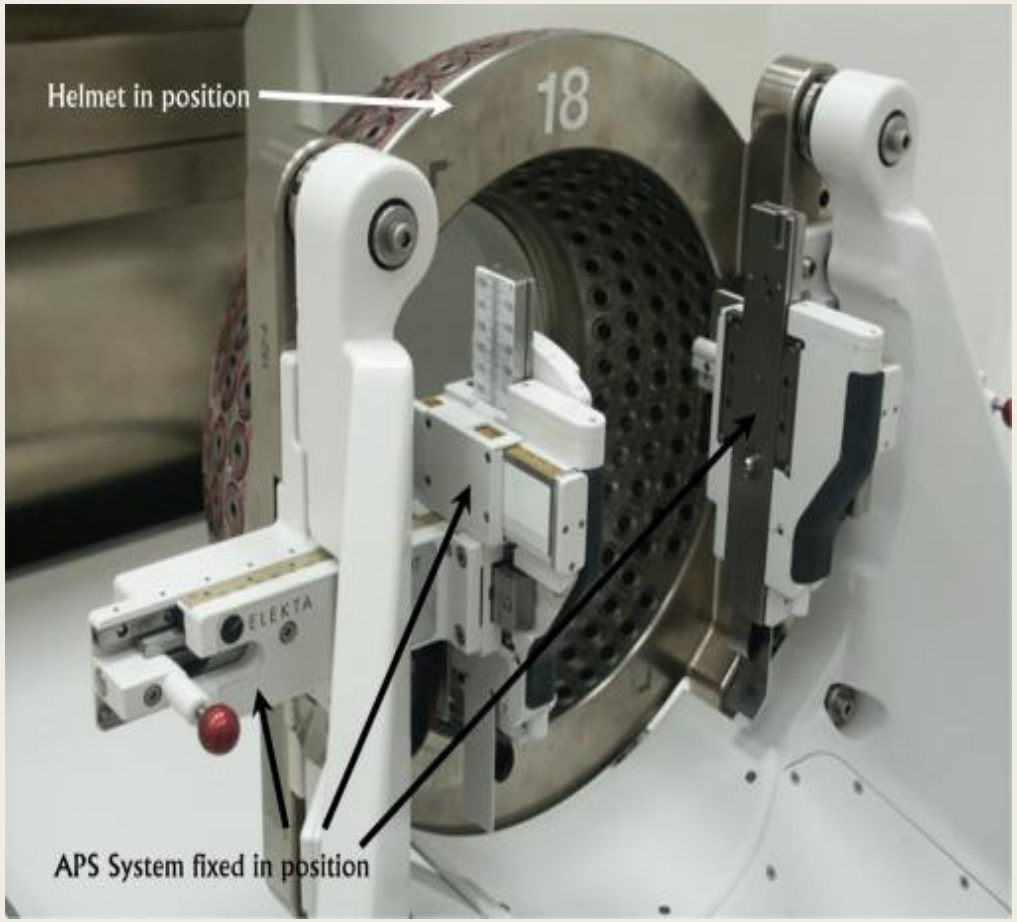
Gamma ray based delivery systems:

- One of the earliest clinically available machines for SRS that remained relevant till now.
- They are known as Leksell Gamma Knife or Gamma units.
- Source: cobalt-60
- Half life : 5.26 years
- Average beam energy: 1.25MeV (1.17 and 1.33 MeV).
- The first Gamma Knife originally developed in 1960.
- Consisted 179 Co-60 sources arranged in a hemispherical fashion covering 70 degree latitude and 160 degree in longitude.
- Beam size at focal point-2.5x 7.5 sqmm.

LGK Models U, B,C/4C:

- These models consist of 201 Co-60 sources arranged in a hemisphere.
- They have internal fixed collimators and an external removable collimator helmet with four different aperture sizes (4, 8, 14, and 18 mm) available at the focus point.
- Only one collimator diameter can be used at a time, and unused sources have to be manually plugged with tungsten plugs.
- Models U and B require manual adjustments for patient positioning and treatment parameters, while Models C and 4C have an automatic positioning system (APS) for repositioning the patient between shots.
- SFD-40cm and mechanical accuracy is about 0.3mm.

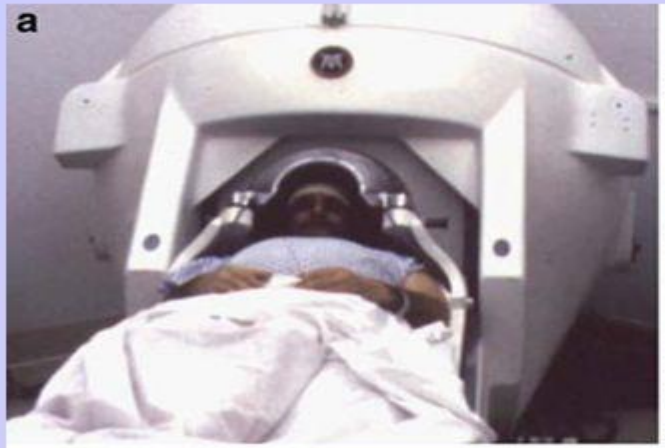



Helmet in position
18
ELEKTA
APS System fixed in position

Gamma Knife Development

Gamma Knife I:

- 179 ^{60}Co sources
-rectangle collimator



U Gamma knife:

- 201 ^{60} Co sources
- Cone collimator

Model B:

- Simpler source change

Model 4C:

-Allow 3D planning
- More efficient helmet change

Courtesy of Dr. Timothy D. Solberg et al. Historical Development of Stereotactic Ablative Radiotherapy

LGK Perfexion:

- Released in 2006, it has 192 Co-60 sources arranged in a conical fashion, resulting in different source-to-focus distances (SFDs) depending on the source position(37.4 cm to 43.3 cm).
- This system uses a tungsten collimator array divided into five concentric rings and eight independently variable sectors. Each sector has 24 sources with three circular collimator sizes (4, 8, and 16 mm).
- It does not require collimator helmets, and collimators are controlled by servo-controlled motors.
- The LGK Perfexion features a robotic treatment couch and patient positioning system, eliminating the need for APS and trunnions.
- The positioning speed is increased compared to previous models, and patient comfort is enhanced with whole-body movement.
- The Extend system is available for multifractionated treatments, using a dental impression and vacuum for immobilization.
- The LGK Perfexion allows for the combination of different beam diameters for the same focal point setup, leading to faster treatment times and more optimal dose distributions.

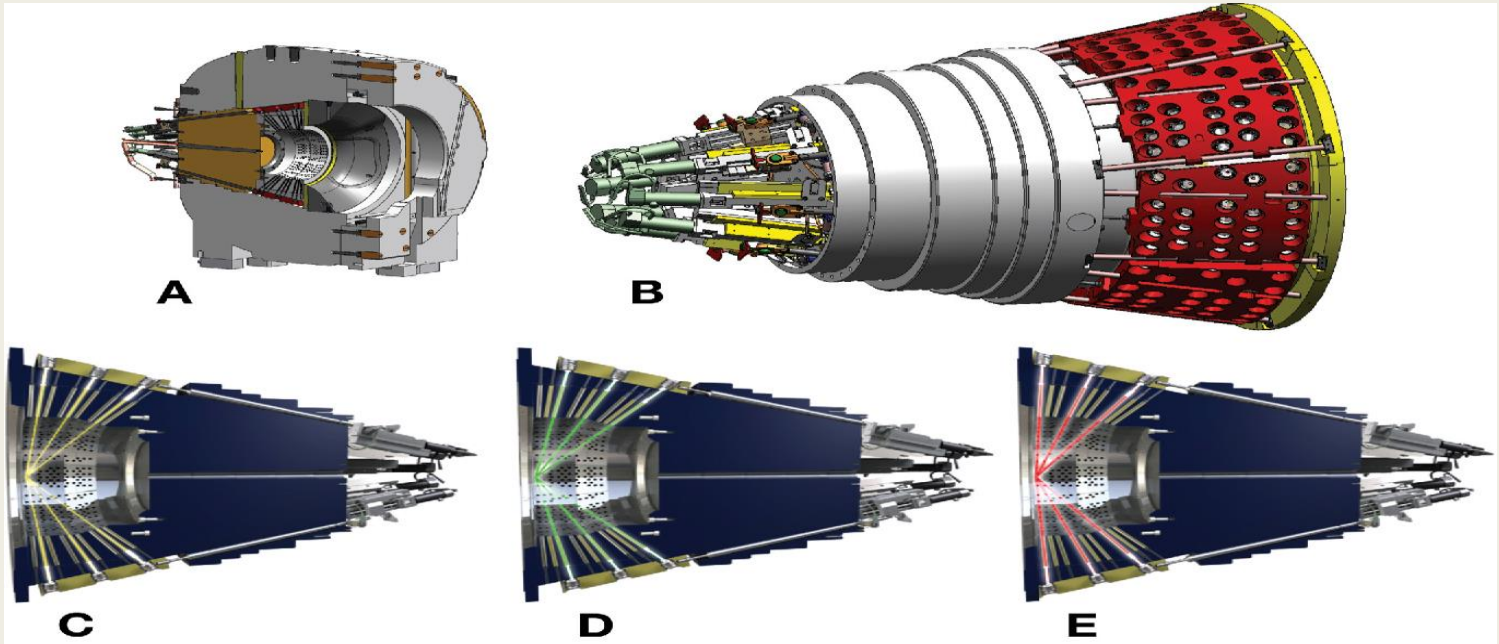


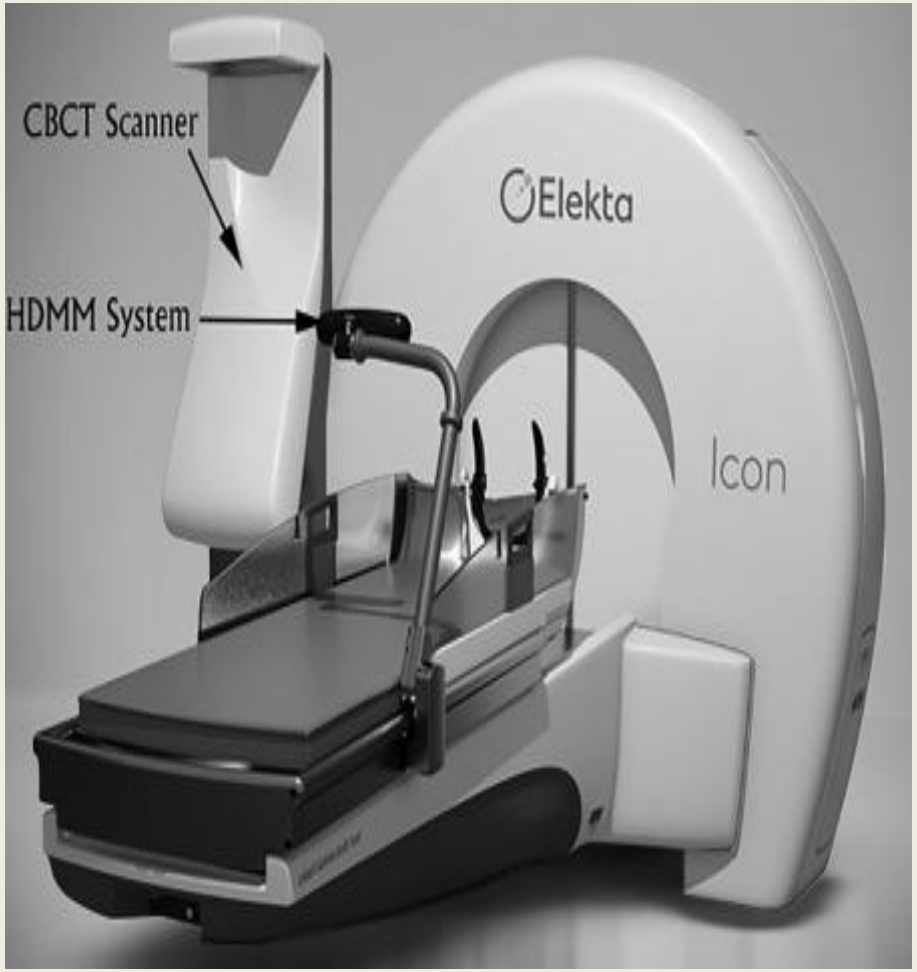
FIG. 1. Leksell GK Perfexion radiation unit and collimator system. A: Cross-section of the Perfexion radiation unit. B: Detailed view of sectors. Each sector holds 24 cobalt-60 sources and can be moved independently of other

LGK Icon:

- The newest addition to the LGK line, it features 3D on-board imaging and patient monitoring capabilities, eliminating the need for a frame.
- Instead, it uses a thermoplastic mask for patient immobilization.
- Additions:1.Gantry with an X-ray source and detector panel.

  2.IFMM tool: IR system for monitoring the motion of pt.
- As cbct is done outside the unit, requires pt to be imaged positioned and then shifted into the treatment position.
- IFMM has 4 IR reference markers(fixed) and one marker on the patients nose.
- Observers relative motion between then and the pt
- When motion beyond a threshold is detected, the treatment is automatically paused to ensure patient safety =Active mode.

- It has another mode in which if motion beyond the threshold is observed, the treatment continues, but a warning message is displayed = Passive mode.



Linac based delivery system:

- Linac-based systems are multipurpose and do not use radioactive material.
- Developed in the 1980s, optimized for SRS/SBRT treatments.
- Features: finer resolution multileaf collimator (MLC), higher dose rates, greater mechanical accuracy, integrated image guidance.
- Modern linacs offer flattening filter-free (FFF) beams with higher dose rates and softer energy spectrum.
- FFF beams combined with noncoplanar beam or arc arrangements allow fast conformal treatments.
- Advantages: high-dose delivery to target, sharp dose gradient, normal tissue sparing, shorter treatment times.
- Fixed circular collimators or cones are tertiary collimators for linacs.
- Cones provide smaller field sizes with sharper penumbra, ideal for spherical/near-spherical brain lesions.

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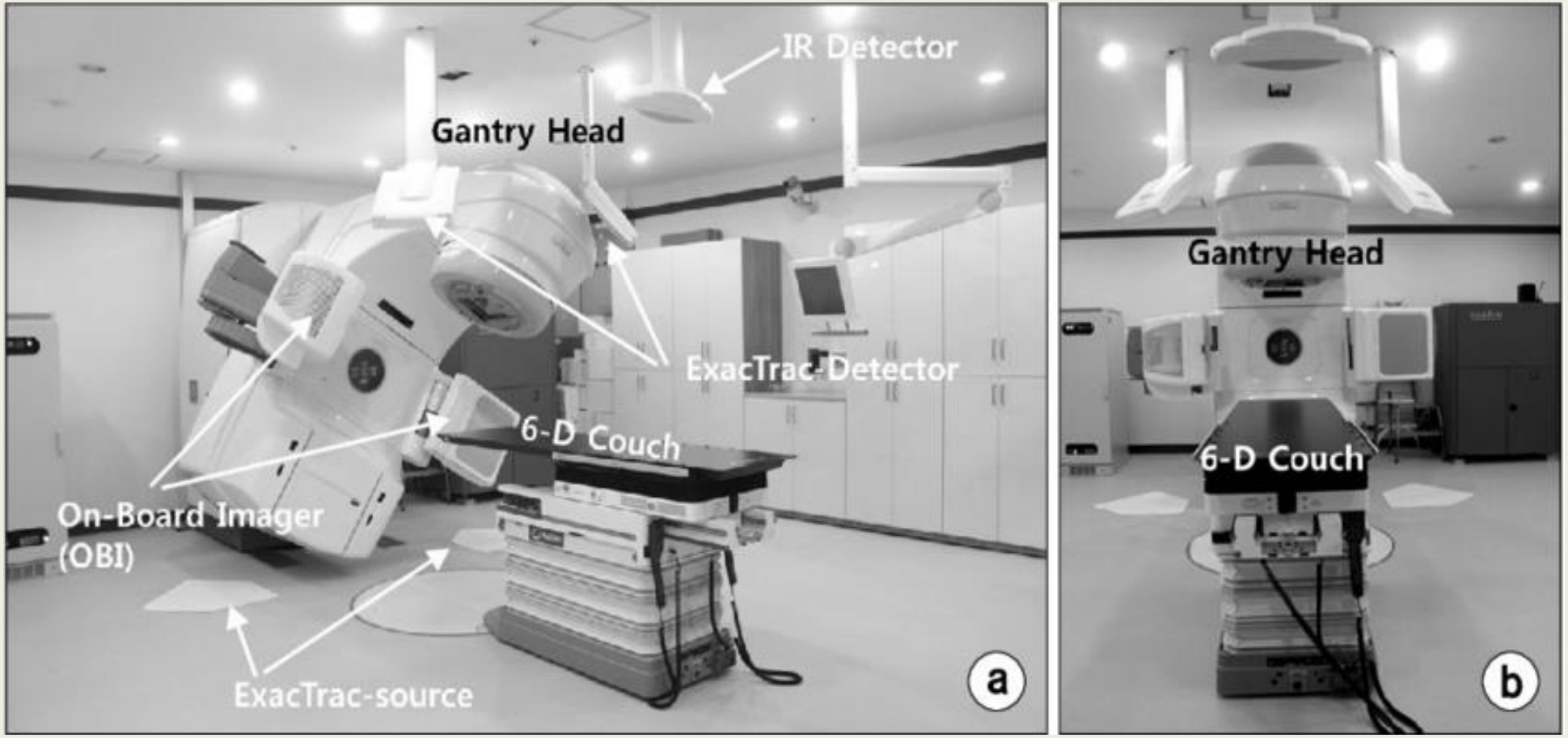
- ICVI system(Integrated Conical Collimator Verification and Interlock) provides automatic jaw setting with cone fixation.
- Penumbra for 6-MV beams from cones is <2 mm at dmax with SAD = 100 cm.
- Add-on devices like MLCs are available for linacs.
- m3 micro-MLC with 26 leaf pairs of varying widths (3, 4.5, 5.5 mm arranged as3,3,14,3,3 pairs).
- Leaves interdigitate, have 12 cm length, 6 cm thickness, can overtravel 5cm and precision 0.1mm
- MLCs travel perpendicular to the beam's central axis with a maximum speed of 1.5 cm/sec.
- Average penumbra for 6-MV fields shaped to 2 × 10 cm2 with m3 is <2.5 mm at dmax with SAD = 100 cm.
- The clearance from isocenter of the m3 system is 31 cm.
- Ancillary devices for patient imaging, positioning, and monitoring are available.
- Respiratory motion management options for SBRT include breath-hold and gated beam systems.
- Use of cones and MLCs allows linacs to achieve SRS-like treatment capabilities.

Varian systems:

Novalis Tx:

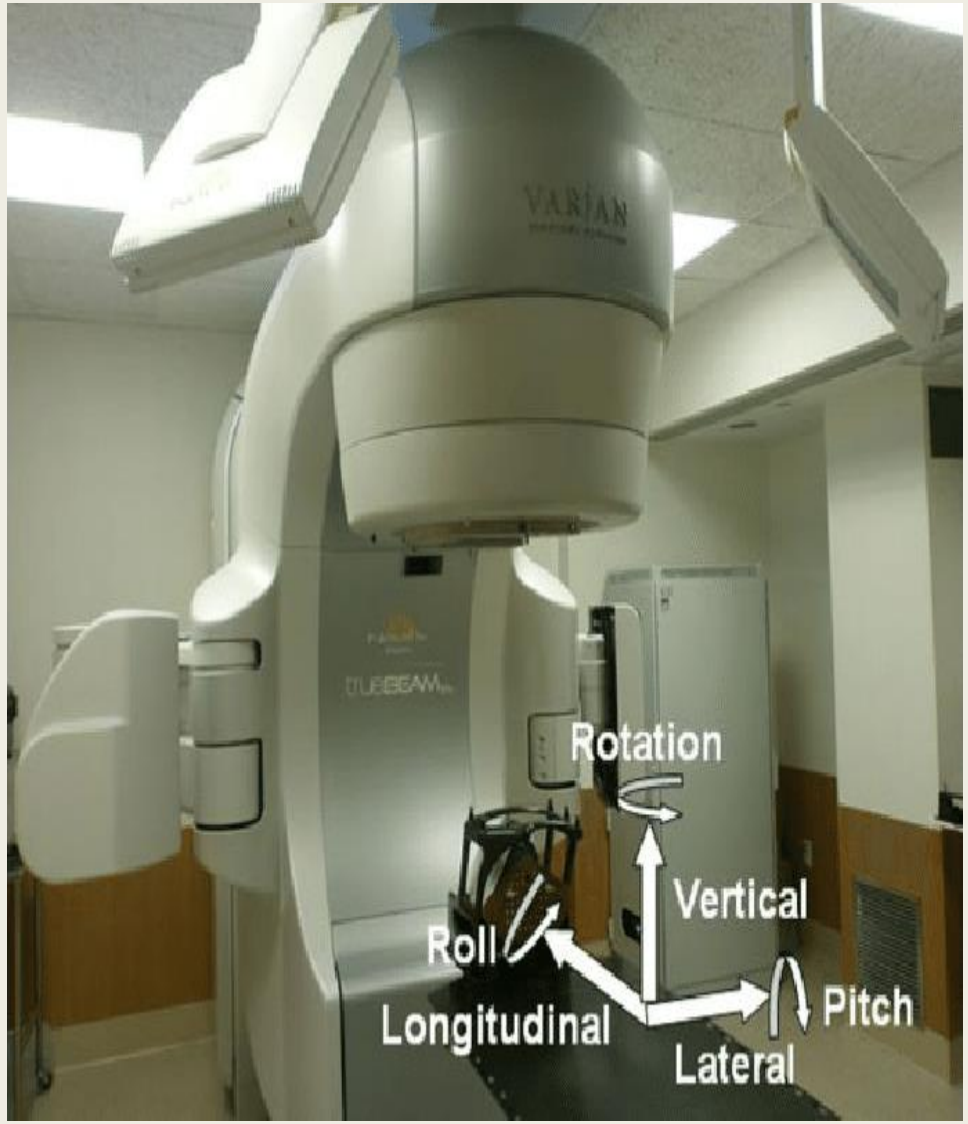
- Developed by Varian and Brainlab.
- Features on-board imaging (MV panel and imaging), high-definition MLC (HDMLC) and Exac Track system.ICVI system can be used with this platform.
- HDMLC- 32 pairs of innerleaves of 2.5mm surrounded by 14 pairs of 5mm on either side.
- Provides 6 MV beam for SRS treatments with a higher dose rate(1000 MU/min) and smaller field size.
- Maximum field size for conventional beams is 40 × 22 cm2.
- Penumbra at dmax for SRS 6 MV is 2.6 mm, for 6 MV is 4.2 mm, and for 10 MV is 6.2 mm.
- ExacTrac provides accurate pt setup and monitoring by two ceiling mounted x-ray panels.
- With a 6-DOF couch, ExacTrac provides optimal treatment position adjustments.



Novalis Tx by varian systems

TrueBeam STx:

- Selectable photon energies from 4 to 20 MV(4, 6, 8, 10, 15, 18, 20) and electron energies from 4 to 22 MeV.
- Offers flattened and FFF beams with higher dose rates for faster treatment delivery.
- Uses HDMLC for field shaping and offers ICVI system as well.
- Similar gantry, collimator, and couch isocenter accuracy as Novalis Tx i.e 0.75 mm.
- Maestro control architecture and redesigned gantry elements for enhanced performance.



Edge:

- Smaller profile TrueBeam linac designed for SRS/SBRT.
- Offers 6 and 10 MV energies with standard and high-dose rate (FFF) modes.
- Uses HDMLC or ICVI system for field shaping.
- Comes with Optical Surface Monitoring System (OSMS) for patient positioning and monitoring.
- Integrated PerfectPitch 6-DOF couch for precise positioning.(accuracy till 0.5mm).
- It allows KV/MV imaging triggered on basis of gantry position, respiratory signals and MU delivered(MV imaging –high contrast 2.5MV mode.
- Offers Calypso system for extracranial real-time tracking of target using EM signals from beacon transponders implanted in the pt.

Elekta systems:

Elekta Synergy S:

- On-board planar kV and CBCT capabilities for patient position verification.
- Beam modulator (BM) head with 40 leaf pairs of 4 mm width at isocentre. There are no back up jaws.
- BM leaves can interdigitate and have a maximum leaf speed of 3 cm/sec.
- Maximum field size with BM is 16 × 21 cm2.
- Penumbra values: approximately 4.5 mm (along leaf motion) and 3.3 mm (perpendicular to leaf motion) for a 4.8 x 5.8 sqcm field.
- Do not provide FFF beams, so maximum dose rate of 600 MU/min is available.

Elekta Versa HD:

- Designed for efficient delivery of conventional and SRS/SBRT treatments.
- Offers both flattened and FFF photon beams (6 MV,10 MV, 15 MV or 18 MV) and electrons (4–15 MeV).
- Maximum dose rate for FFF beams: 1,400 MU/min for 6 MV and 2,400 MU/min for 10 MV.
- Equipped with the Agility collimator with 80 interdigitating leaf pairs of 5 mm width at isocenter.
- Agility collimator has a maximum leaf speed of 3.5 cm/sec (effective speed of 6.5 cm/sec) and 15 cm overtravel.
- Tow y shaped diaphragms run perpendicular to leaves to allow rapid field changes.
- Penumbra value for a 6-MV beam at dmax and SAD = 100 cm is 4.8 mm for a 10 × 10 cm2 field.
- 4D soft-tissue visualization with on-board imaging system for dynamic real-time tumor tracking.
- Gantry, collimator, and treatment couch isocentricity: 1 mm, 0.7 mm, and 0.7 mm, respectively.

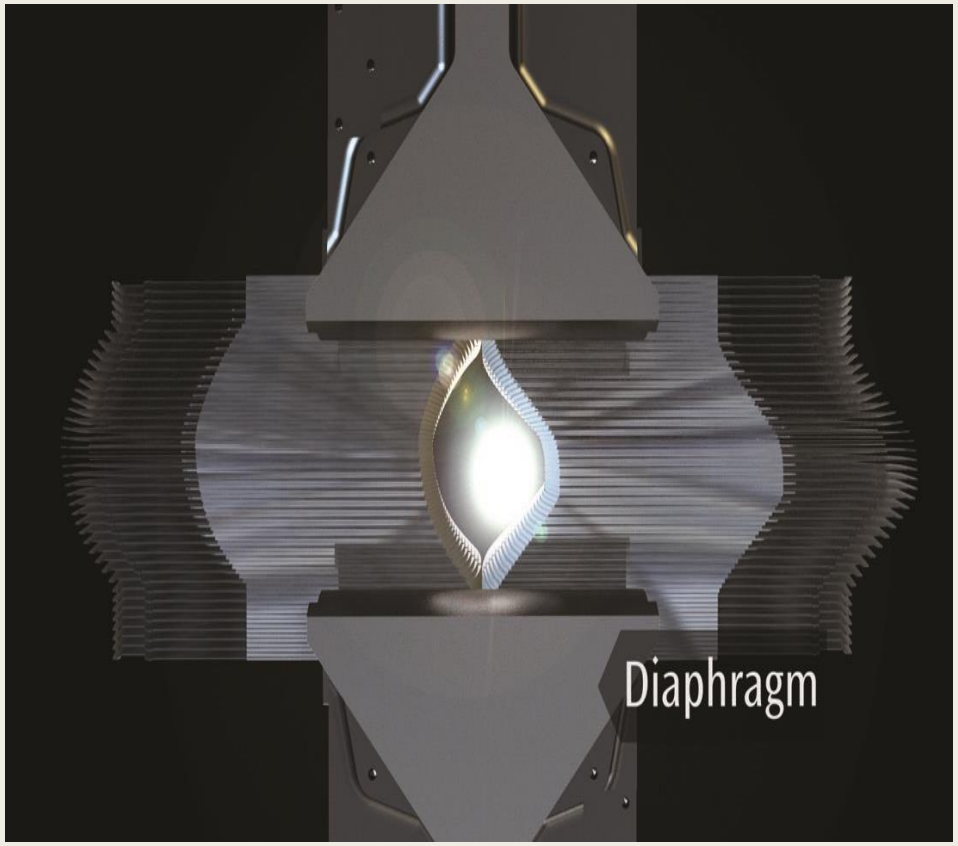


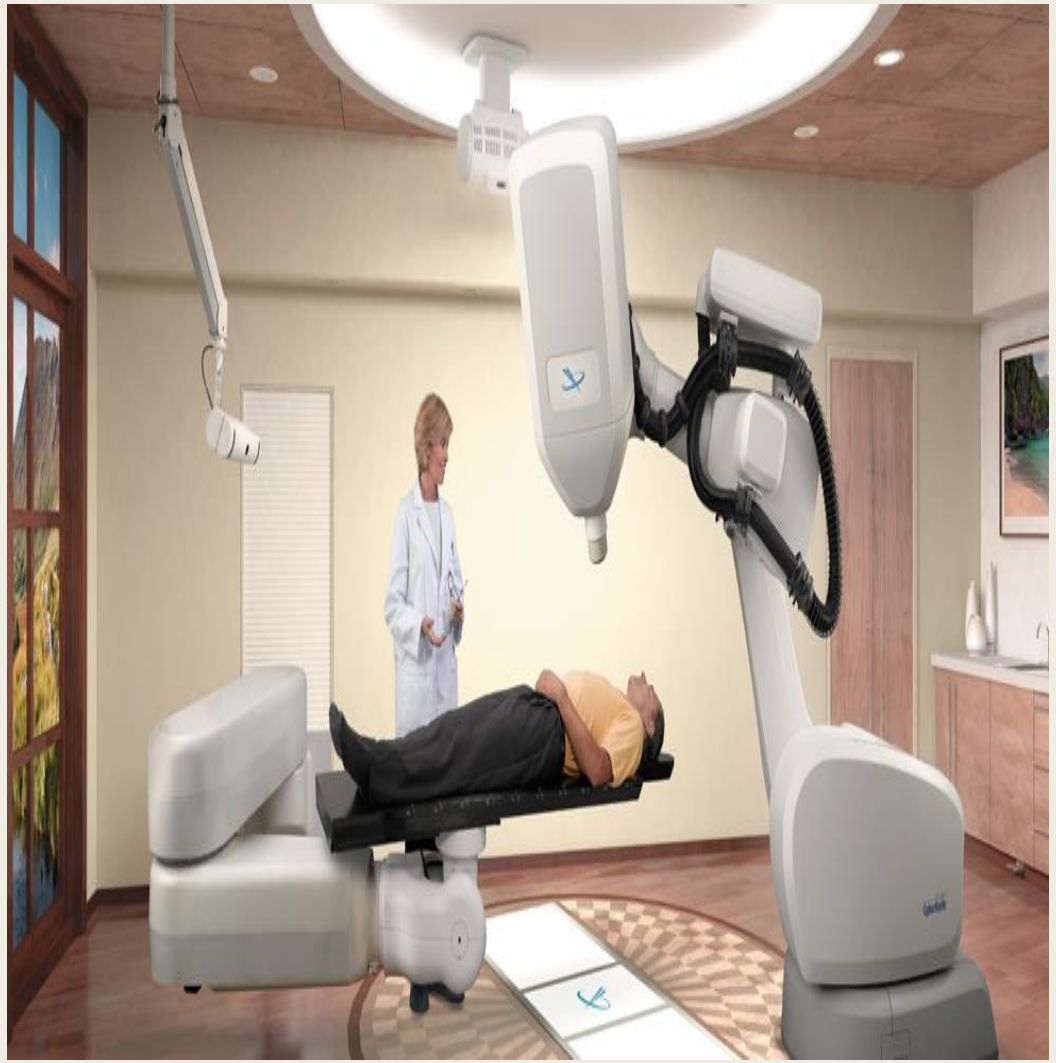
FIGURE 7.7 The Agility collimator with MLC, dynamic leaf guides, and sculpted diaphragms from the patient's eye

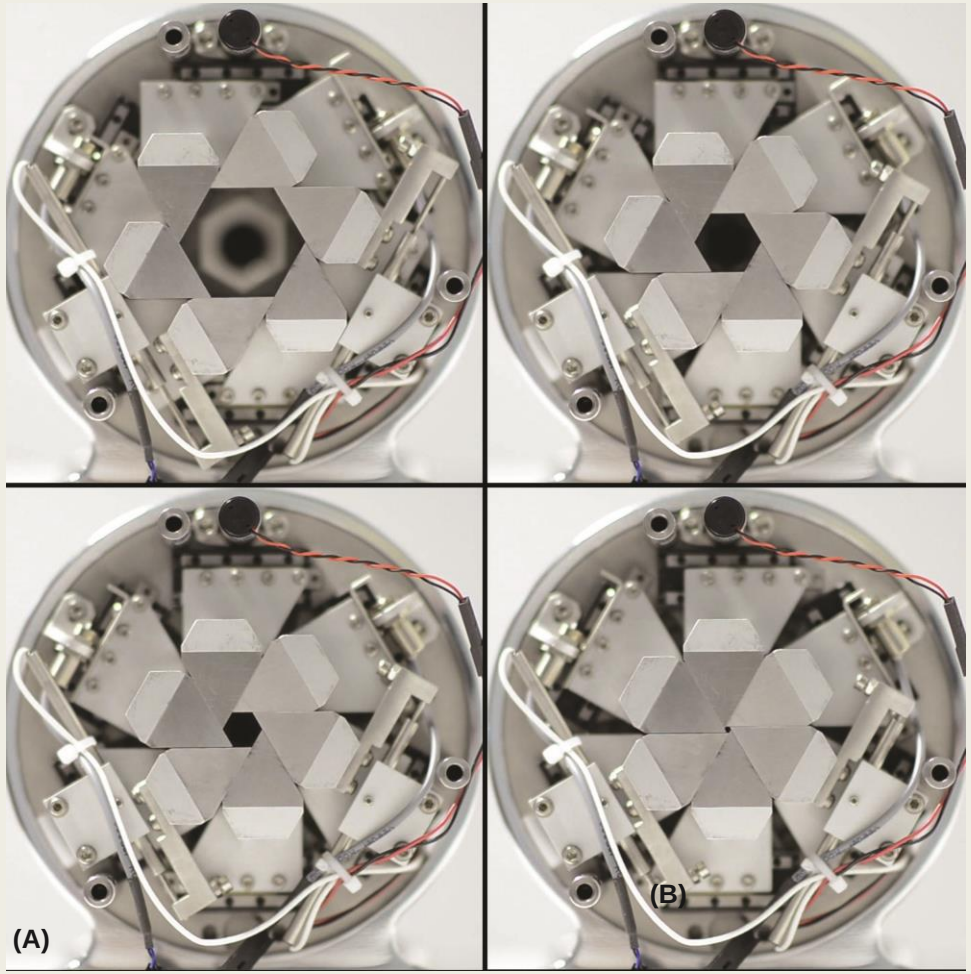
CyberKnife:

- The CyberKnife system by Accuray features a linac mounted on a robotic arm with 6 degrees of freedom, enabling nonisocentric treatments from over 1,200 different directions (up to 1,600 in newer models).
- Key features:
- X-band waveguide design, making the linac small and lightweight (approximately 160 kg).
- Delivers 6 MV FFF radiation beam with a dose rate of 1,000 MU/min at SAD = 80 cm.
- Capable of highly conformal dose distributions without sacrificing dose homogeneity.
- Beam shaping by InCise MLC and Iris variable aperture collimator.
- Integrated image guidance for real-time tracking and positioning correction based on patient anatomy or internal fiducial markers.
- Three tracking methods: bony structure tracking (for intracranial lesions), fiducial tracking and soft tissue tracking (Xsight Lung).

Collimation options:

- Standard fixed circular collimators with sizes ranging from 5 to 60 mm.
- Iris variable aperture collimator, providing fields equivalent to fixed circular collimators but with automatic size changes for reduced treatment times.
- InCise MLC system, with leaves of 2.5 mm width, capable of full overtravel and interdigitation, and capable of providing a maximum field size of 11.5 cm x 10 cm.





(A) Iris collimator

(B) Incise MLC

View Ray:

- The first commercially available MR-guided radiation therapy system.
- It uses three Co-60 heads mounted on a rotating gantry, positioned 120° from each other, and operates with a magnetic field strength of 0.35 T. This design avoids the issues associated with magnetic fields in linac-based systems.

Key features:

- Dose rate of 550 cGy/min at isocenter with a 10.5 × 10.5 cm^2 field.
- MLC for field shaping with 10 mm wide leaves and a maximum treatment field size of 27 × 27 cm^2.
- Imaging volume is a 50-cm-diameter sphere around isocenter.
- ViewRay adaptive RT treatment planning system offers options to calculate doses with and without the effects of the magnetic field.
- Capable of autocontouring, Monte Carlo dose calculations, IMRT, and on-couch adaptive RT based on daily treatment images.

Clinical applications:

- Beneficial for SBRT due to tumor tracking capabilities, for highly mobile targets with smaller margins.
- Comparible planning studies for lung and liver SBRT to linac-based plans but with inferior quality, such as worse conformity indexes and larger low-dose spillage.

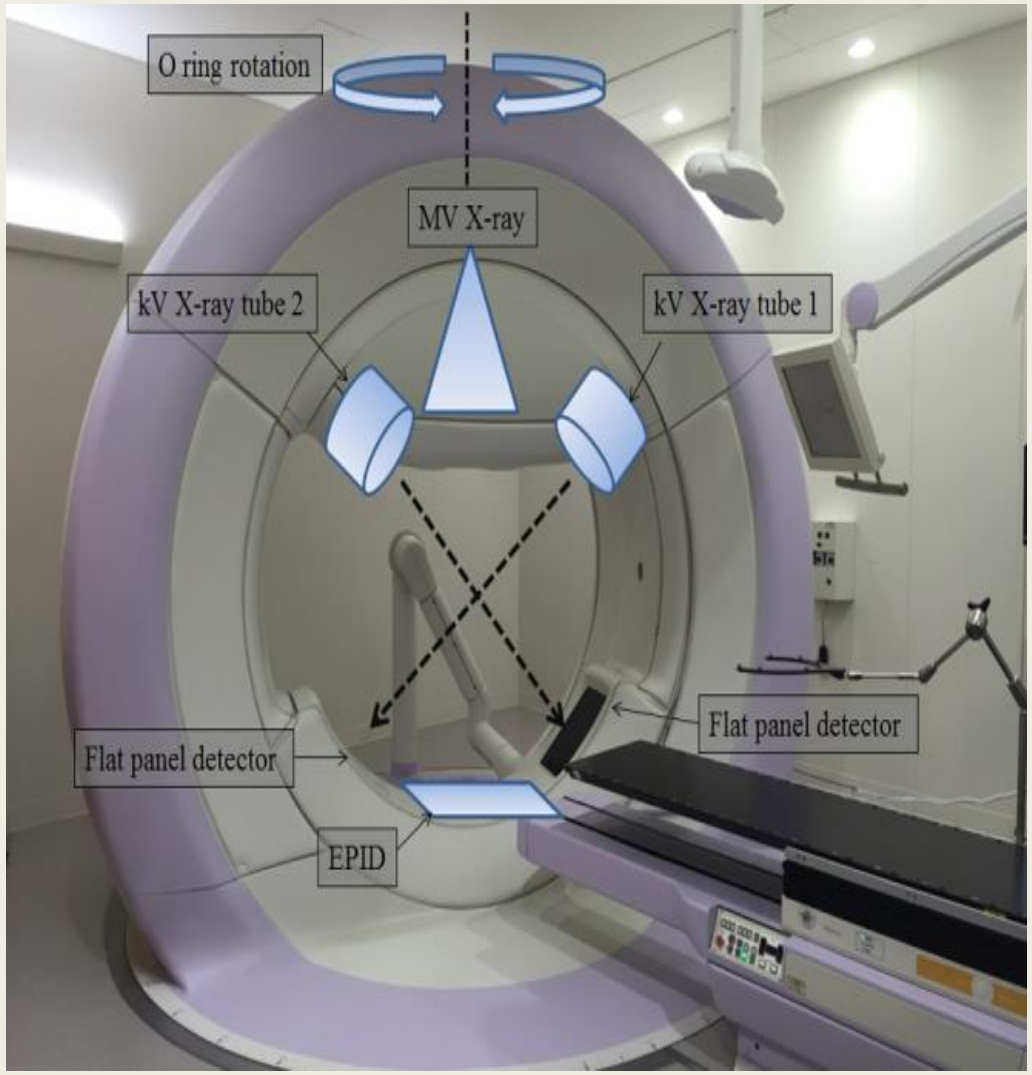
Vero systems:

- The Vero, also known as MHI TM-2000, is a collaborative product between Brainlab and Mitsubishi Heavy Industries Ltd. It is primarily used for SBRT.

  Key features of the Vero system:

- Gimbaled ring gantry with 6 MV beam delivery with integrated KV and MV imaging capabilities
- The source can rotate ±185° around the ring at a speed of 7° per second.
- The ring itself can rotate ±60° at a speed of 3° per second.
- The source can pan and tilt independently ±2.5° at a speed of 9° per second, allowing motion of ±4.2 cm from isocenter along in-plane or cross-plane directions.
- The system includes an ExacTrac robotic couch top for adjusting couch rotations along the lateral and longitudinal axes.

- The linac uses an inline C-band standing waveguide operating at 5.7 GHz to accelerate electrons.
- Field shaping is achieved through 30 pairs of 11-cm-thick tungsten alloy MLC leaves with a width of 5 mm at isocenter.
- The system is equipped with two x-ray tubes and amorphous silicon panel detectors for stereoscopic imaging or CBCT acquisition.
- ExacTrac allows dynamic tumor tracking based on external marker motion, enabling accurate irradiation of moving tumors.
- DWA delivery (by simultaneous rotation of ring and source) has been successful in SBRT.



TomoTherapy systems:

- The Hi-Art I prototype, was the first dedicated IMRT machine with integrated on-board imaging introduced in the clinic in 2003.
- It utilizes a helical treatment delivery approach similar to helical CT scanners.
- The system consists of a 6-MV linac mounted on a slip-ring gantry that rotates fully around the patient, allowing for precise treatment delivery by SAD technique.
- Binary 64-leaf collimator (0.625cm wide) with pneumatic drives for additional modulation and precise dose distribution.
- On-board imaging with a 3.5-MV beam detector array for patient setup verification.
- TomoDirect mode for treatment deliver with static field at discrete gantry angles.
- TomoEDGE feature to minimize penumbra broadening in cranio caudal ends (longitudinal) by the use of dynamic superior and inferior jaws.

- Dose control system for stable output with reduced variations.
- Treatment planning using both KVCT and MVCT imaging and motion monitoring techniques (IR marking system and fluoroscopy) .
- Makes TomoTherapy suitable for carrying SBRT and SRS effectively.

	Gamma-Ray–Based Systems			Linear Accelerator–Based Systems						
	Model C	Perfexion	Icon	Varian Novalis Tx	Varian TrueBeam STx and Edge	Elekta Synergy S	Elekta Versa HD	Vero	Tomotherapy	CyberKnife
Treatment site	Intracranial	Intracranial	Intracranial	Intracranial or extracranial	Intracranial or extracranial	Intracranial or extracranial	Intracranial or extracranial	Extracranial	Intracranial or extracranial	Intracranial or extracranial
Treatment type	SRS	SRS/ SRT	SRS/SRT	SRS/SRT SBRT	SRS/SRT SBRT	SRS/SRT SBRT	SRS/SRT SBRT	SBRT (SRS being investigated)	SRS/SRT SBRT	SRS/SRT SBRT
Immobilization	Frame (head pins)	Frame (head pins or dental fi xation with Extend)	Frameless—thermoplastic mask, or framed							
On-board imaging	No	No	Yes—CBCT (not at isocenter)	Planar kV, CBCT, planar MV	Planar kV, CBCT, planar MV	Planar kV, CBCT, planar MV	Planar kV, CBCT, planar MV	Stereoscopic kV, CBCT, planar MV	Yes—MVCT	Orthogonal kV
Motion tracking	No	No	IR markers	ExacTrac	Surface imaging	kV imaging	kV imaging	IR markers + stereoscopic kV imaging	No	LED markers + orthogonal kV imaging
Source to axis distance	40 cm	Variable: 37.4–43.3 cm	Variable: 37.4–43.3 cm	100 cm	100 cm	100 cm	100 cm	100 cm	85 cm	80 cm
Field sizes	4, 8, 14, 18 mm	4, 8, 16 mm	4, 8, 16 mm	Circular collimators: 4, 5, 7.5, 10, 12.5, 15, 17.5 mm; m3: 10.2×10 cm^2	Circular collimators: 4, 5, 7.5, 10, 12.5, 15, 17.5 mm; HDMLC: 40×22 cm^2	Standard: 40×40 cm^2; BM: 16×21 cm 2	Agility: 40×40 cm 2	Maximum: 15×15 cm^2	Maximum: 1, 2.5, or 5 × 40 cm^2 at isocenter	Circular collimators: 5, 7.5, 10, 12.5, 15, 20, 25, 30, 35, 40, 50, and 60 mm; MLC maximum: 11.5 10 cm^2

	Gamma-Ray–Based Systems			Linear Accelerator–Based Systems						
	Model C	Perfexion	Icon	Varian Novalis Tx	Varian TrueBeam STx and Edge	Elekta Synergy S	Elekta Versa HD	Vero	Tomotherapy	CyberKnife
Field shaping	Circular collimators	Circular collimator 0.29 ± mm	Circular collimator	Fixed circular collimators, multileaf collimator	Fixed circular collimators, multileaf collimator	Fixed circular collimators, multileaf collimator	Fixed circular collimators, multileaf collimator	Multileaf collimator	Binary multileaf collimator	Fixed circular collimators, variable aperture collima- tor (Iris), multileaf collimator (InCise)
	Noncombinable	Combinable	Combinable	m3 MLC: 3, 4.5, 5.5 mm	HDMLC: 2.5, 5 mm	Standard: 10 mm; BM: 4 mm	Agility: 5 mm	5 mm width at SAD	6.25 mm width at SAD	MLC: 3.85 mm width at SAD
Patient positioning	Manual/automatic (limited range of motion)	Automatic	Automatic	Standard couch: translates and yaws; 6-DOF couch: translations and three rotations	Standard couch: translates and yaws; 6-DOF couch: translations and three rotations	Standard couch: translates and yaws; 6-DOF couch: translations and three rotations	Standard couch: translates and yaws; 6-DOF couch: translations and three rotations	Couch translates, pitch + roll (no yaw)	Couch translates	Standard couch: It has 5 DOF. Robotic couch: It has 6 DOF
Positioning accuracy	0.3 mm (mechanical accuracy)	<0.05 mm	0.2 mm (CBCT and Treatment isocenter coincidence)	≤0.75 mm radius (gantry, collimator, couch isocentricity per vendor)	≤0.75 mm radius (gantry, collimator, couch isocentricity per vendor)	<1 mm	0.5, 0.35, 0.35 mm radius for gantry, collimator, couch, respectively (Narayanasamy 2016 [35])	0.5 mm isocenter accuracy per vendor	<0.4 mm mechanical isocenter stability per vendor	0.1 (Antypas [44])
Maximum dose rate	Varies with source strength ~300 cGy/min (Lee 2015 [109])			Standard beams: 600 MU/min, 6 MV. SRS: 1,000 MU/ min	FF: 600 MU/ min; 6 MV FFF: 1,400 MU/min; 10MV FFF: 24,000 MU/min	600 MU/min	FF: 600 MU/min; 6MV FFF: 1,400 MU/min; 10MV FFF: 24,000 MU/min	500 MU/min	850 MU/min	1,000 MU/ min

THANK YOU