Cyberknife

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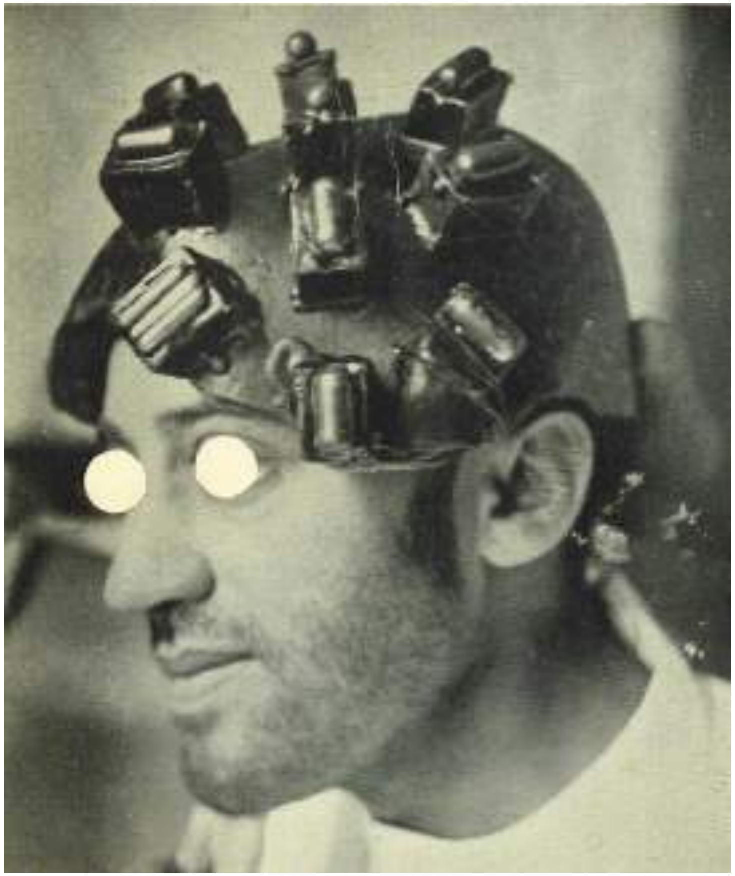
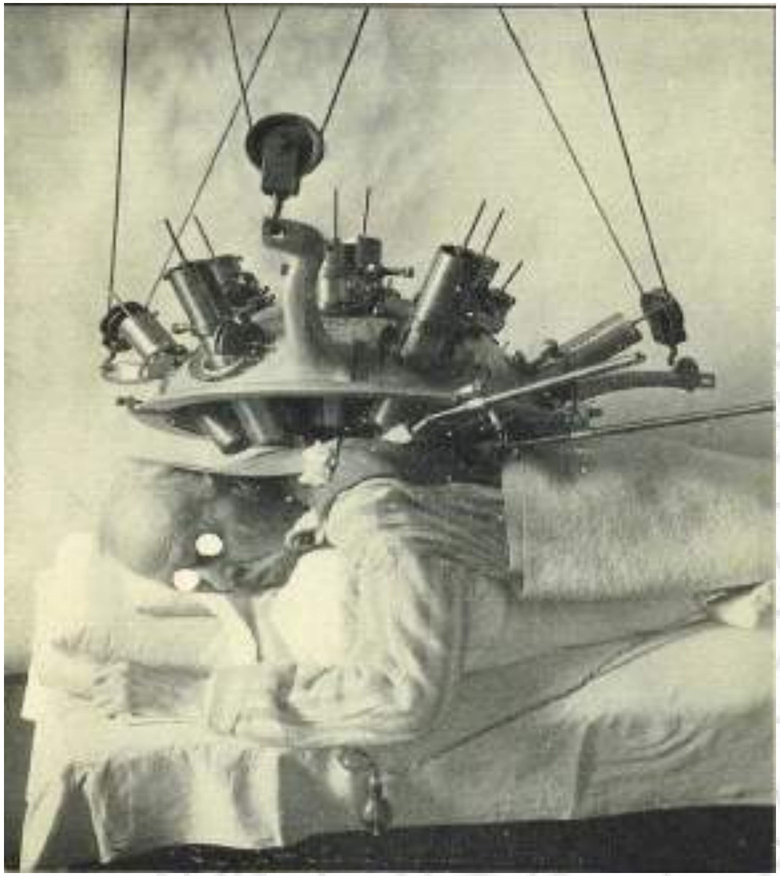
... ومن العلم حياة
Knowledge Into Action

- Disclosure:

  I have no disclosure to declare.

Radium Bomb (Kasr El Ainy in the 1930’s)





Zaghloul & Bishr Int J Radiat Oncol Biol Phys, 2018

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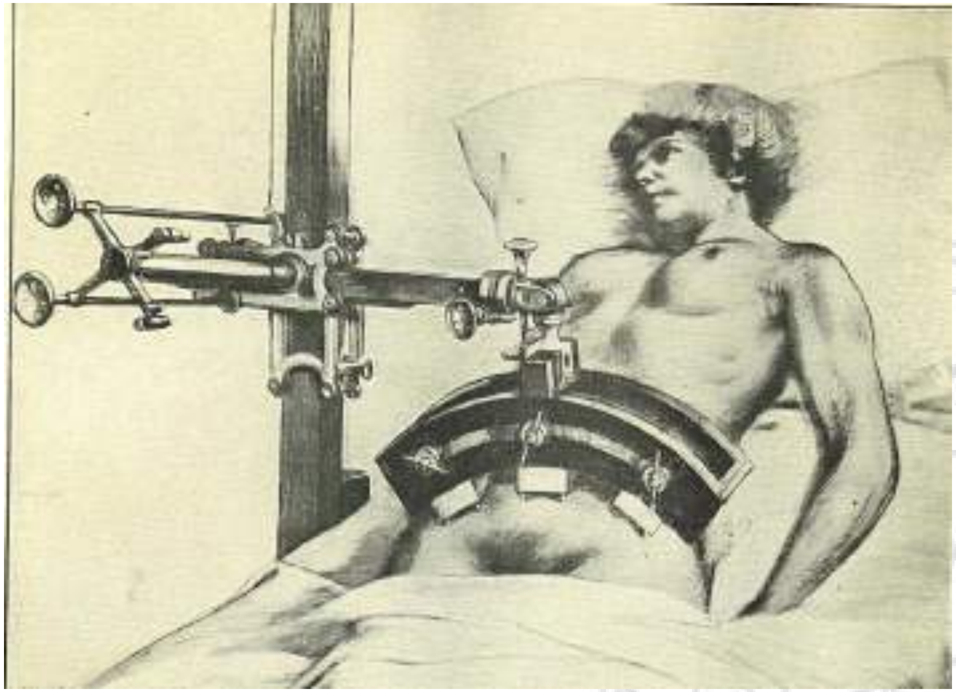

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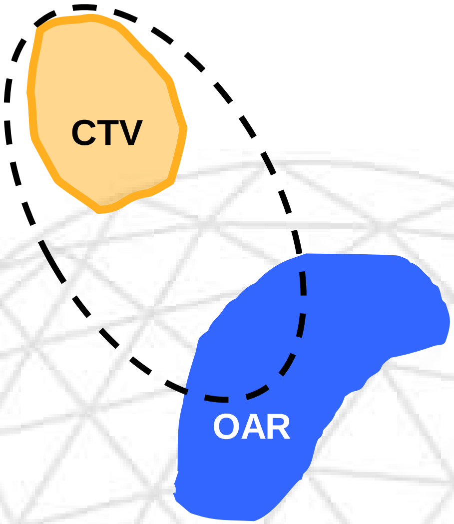
External Beam Irradiation

Why we need a PTV margin

- Margins are needed to account for uncertainties such as
  - Motion during treatment
  - Daily variations of motion
  - Volume changes (growth, shrinkage)
  - Heart, beating, GI-motion,...
  - Patient setup errors (3-5 mm)



First Human Stereotacic frame(1946)

Henry Wycis

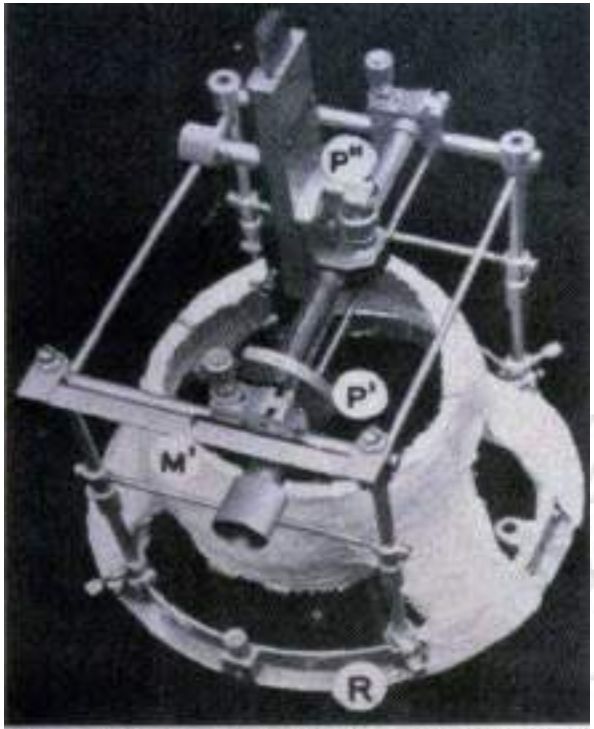
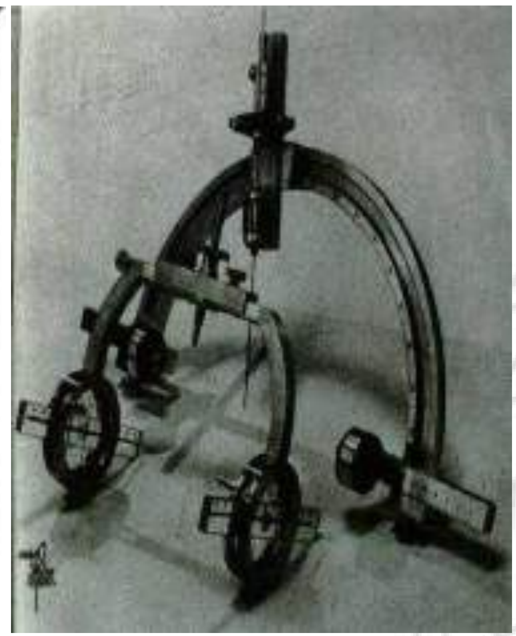
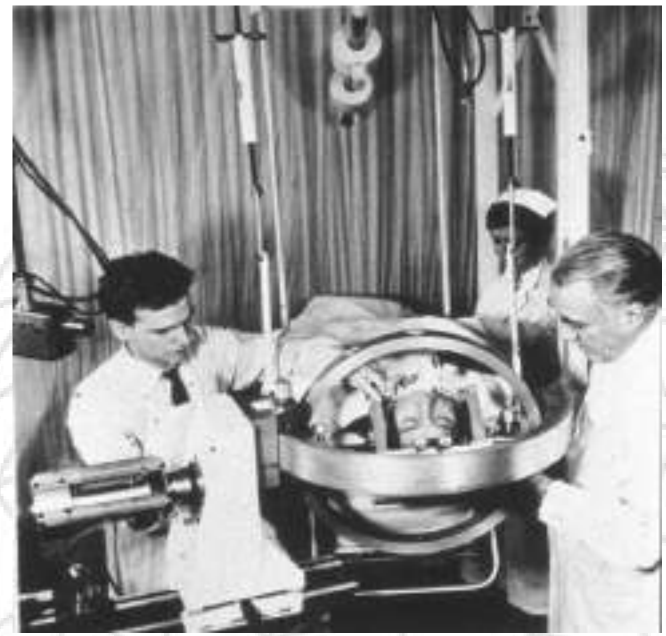


Figure 1.2. Spiegel and Wycis' original human stere

Ernest Spiegel

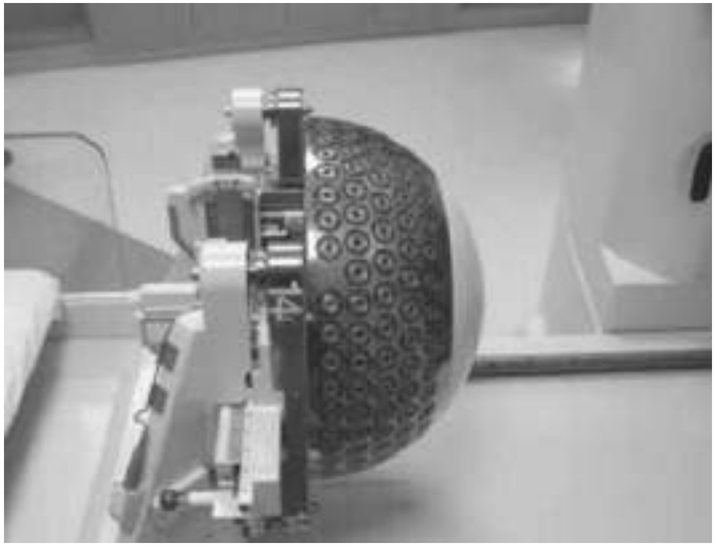
First Human Stereotacic frame 1946

Laksel invented the Gammaknife (1958)

Lars Leksell

First Gamma Knife (1968)



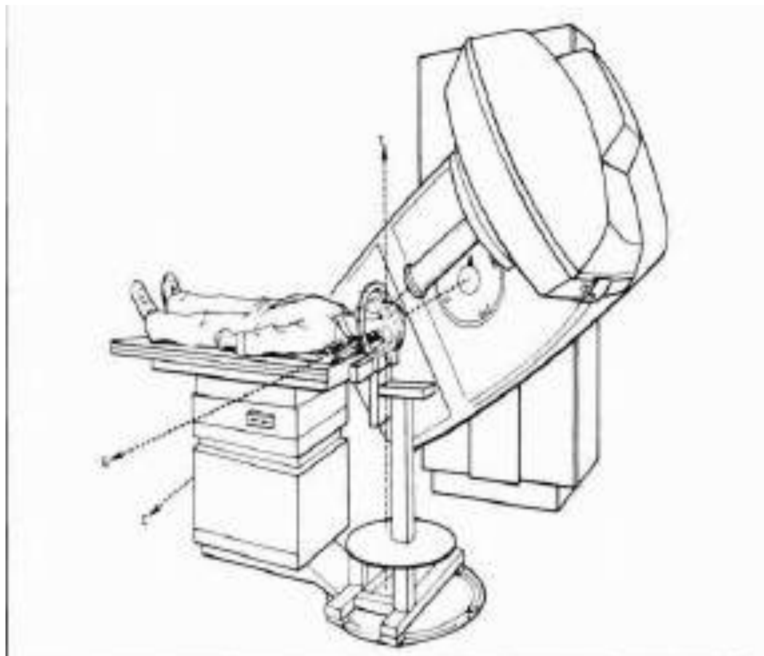
-1968, SophiahemmetHospiatl in Stockholm , Sweden.

- 197 sources CO-60

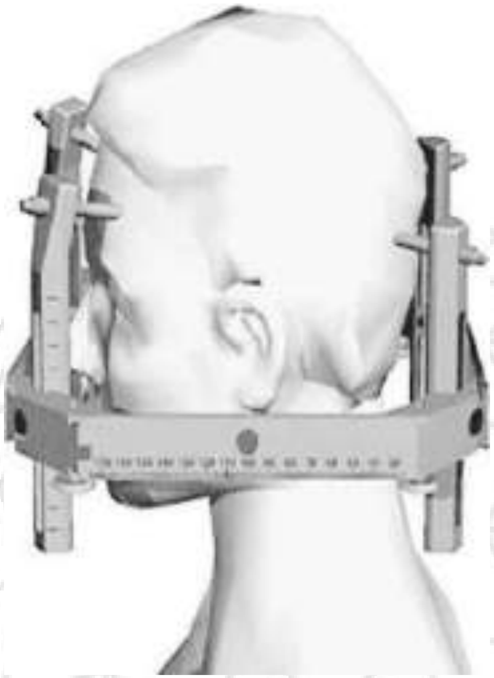
Linac Radiosurgery (1988)

Linear Accelerator as a Neurosurgical Tool for Stereotactic Radiosurgery

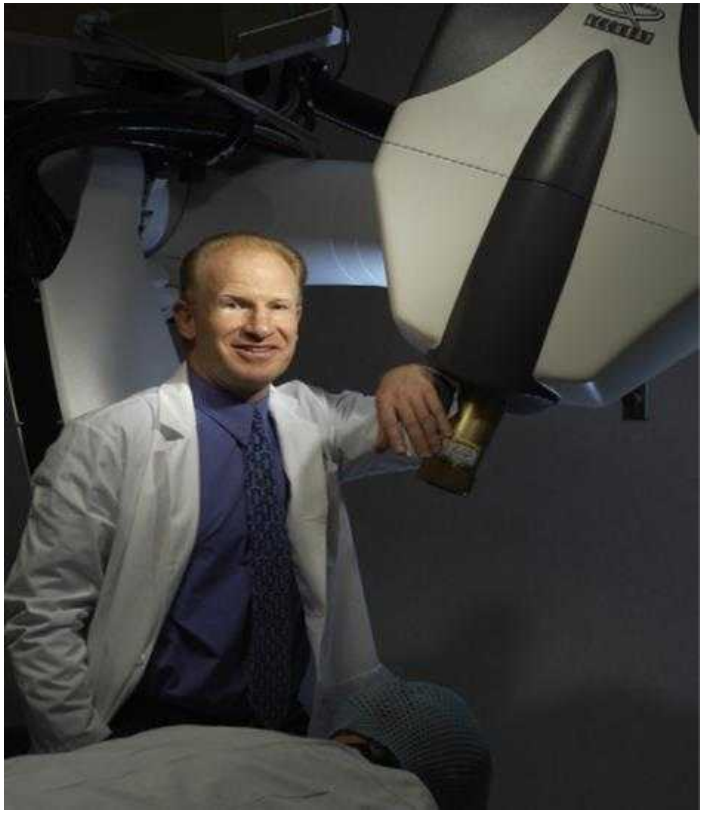
Ken R. Winston, M.D., and Wendell Lutz, Ph.D.



Linac Invasive Frame



The Cyberknife was invented in 1990 by ***John R. Adler***



1st delivery at Stanford

First Patient: June 6, 1994
(Stanford University)

Radiosurgery

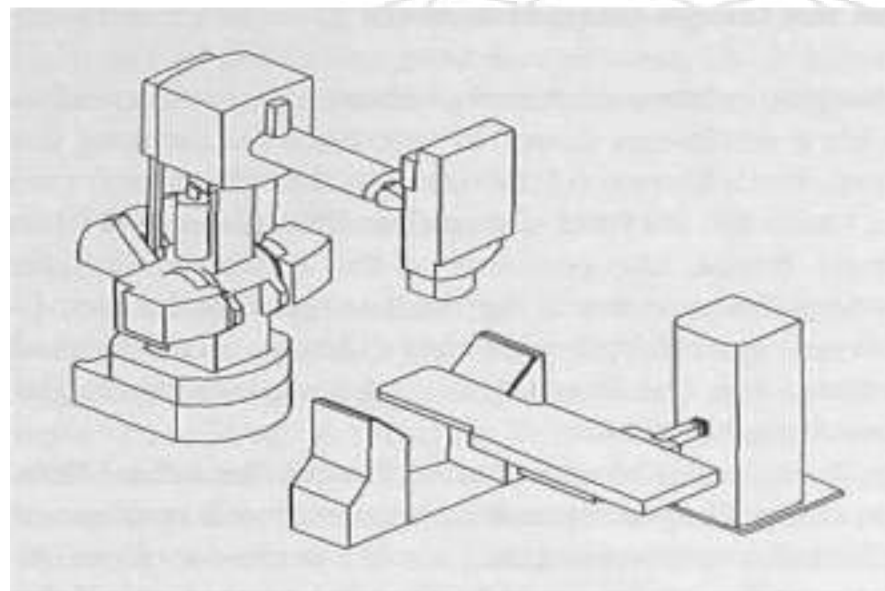
XIIth Meet World Soc Stereotact Funct Neurosurg, Lyon 1997
Stereotact Funct Neurosurg 1997;69:124–128

Stereotactic and Functional Neurosurgery

The Cyberknife: A Frameless Robotic System for Radiosurgery

John R. Adler, Jr.[a,b], *Steven D. Chang*[a], *Martin J. Murphy*[b], *James Doty*[a,c], *Paul Geis*[b], *Stephen L. Hancock*[b]

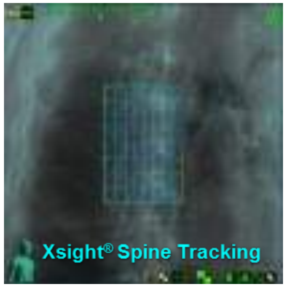
Departments of
[a] Neurosurgery and
[b] Radiation Oncology, Stanford University Medical Center, Stanford, Calif., and
[c] Newport Radiosurgery Center, Newport Beach, Calif., USA

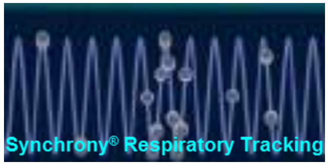


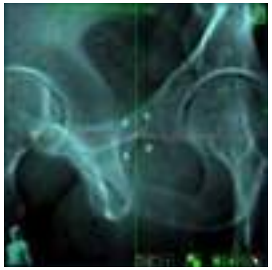
Cyberknife

- It provides pain-free, non-surgical option for patients who have inoperable or surgically complex tumors.
- No anesthesia or hospitalization needed
- Greater comfort (patient can breathe normally during treatment, No breath hold)
- Little or no recovery time
- Immediate return to normal activities

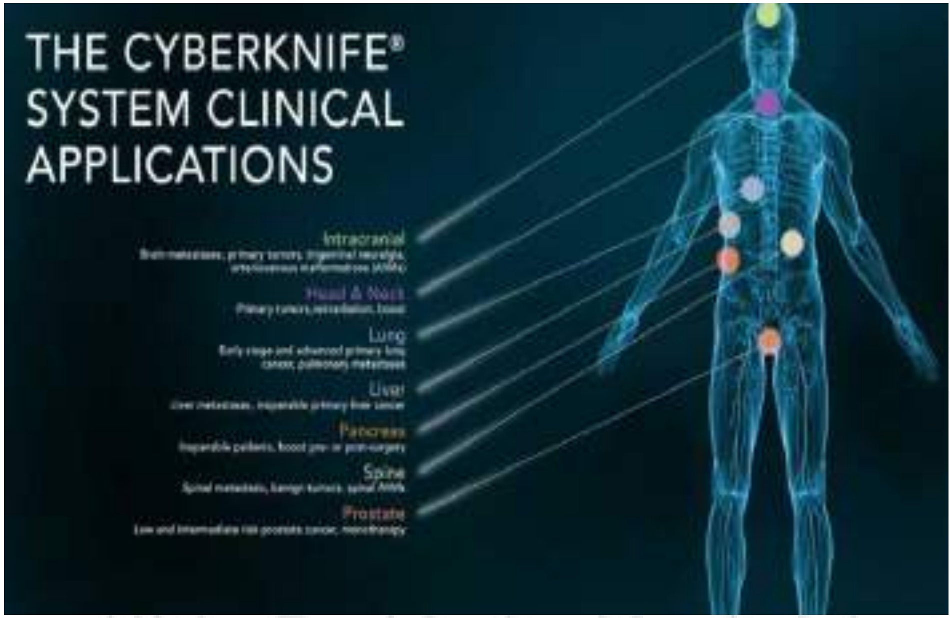
Full body Radiosurgery (SRS) and SBRT

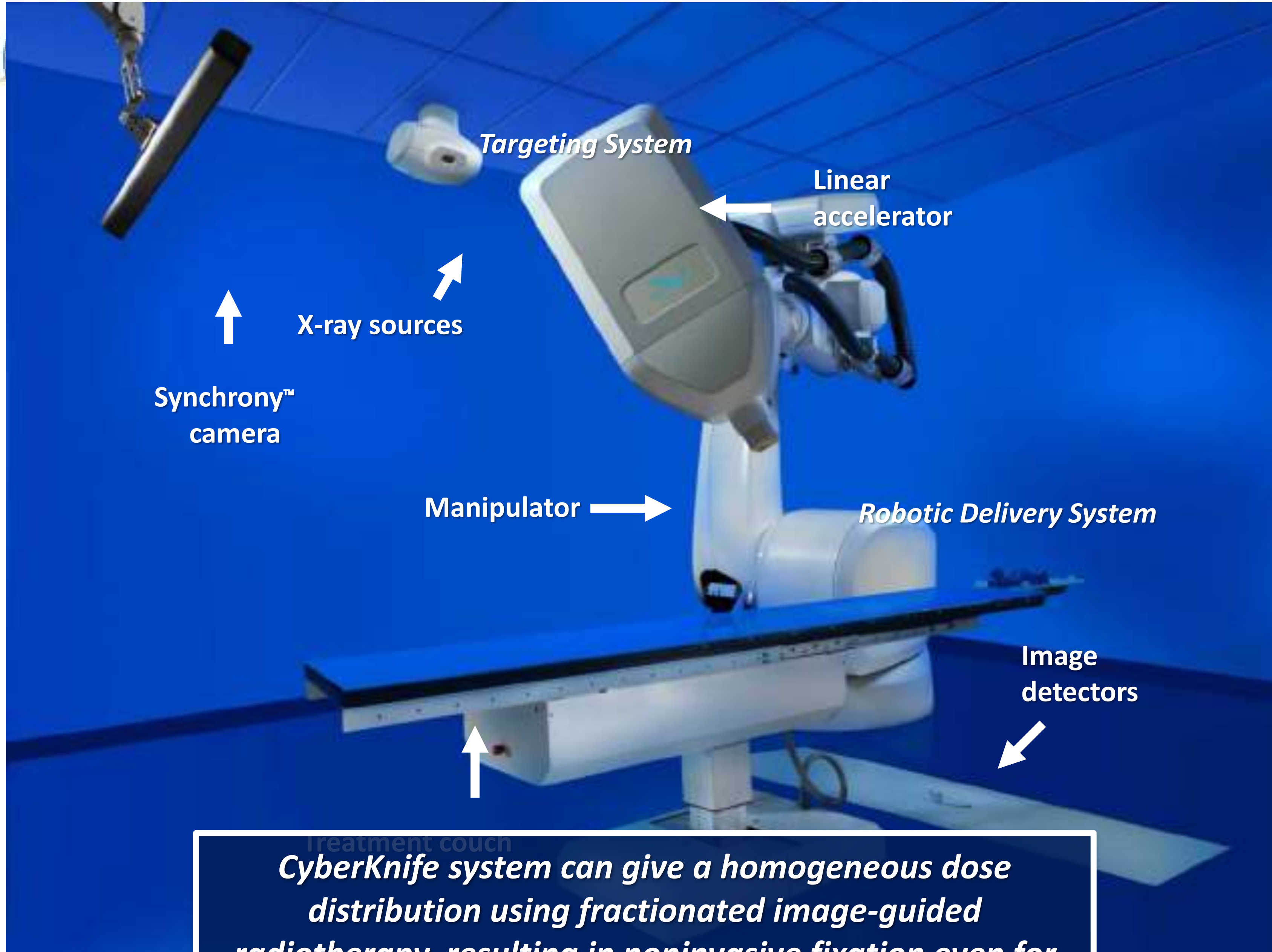






Fiducial Tracking





CyberKnife system can give a homogeneous dose distribution using fractionated image-guided radiotherapy, resulting in noninvasive fixation even for other than cranial lesions

Cyberknife Components

- Manipulator.
- Linac.
- Collimator.
- Imaging System
- Couches.
- Treatment Planning System.

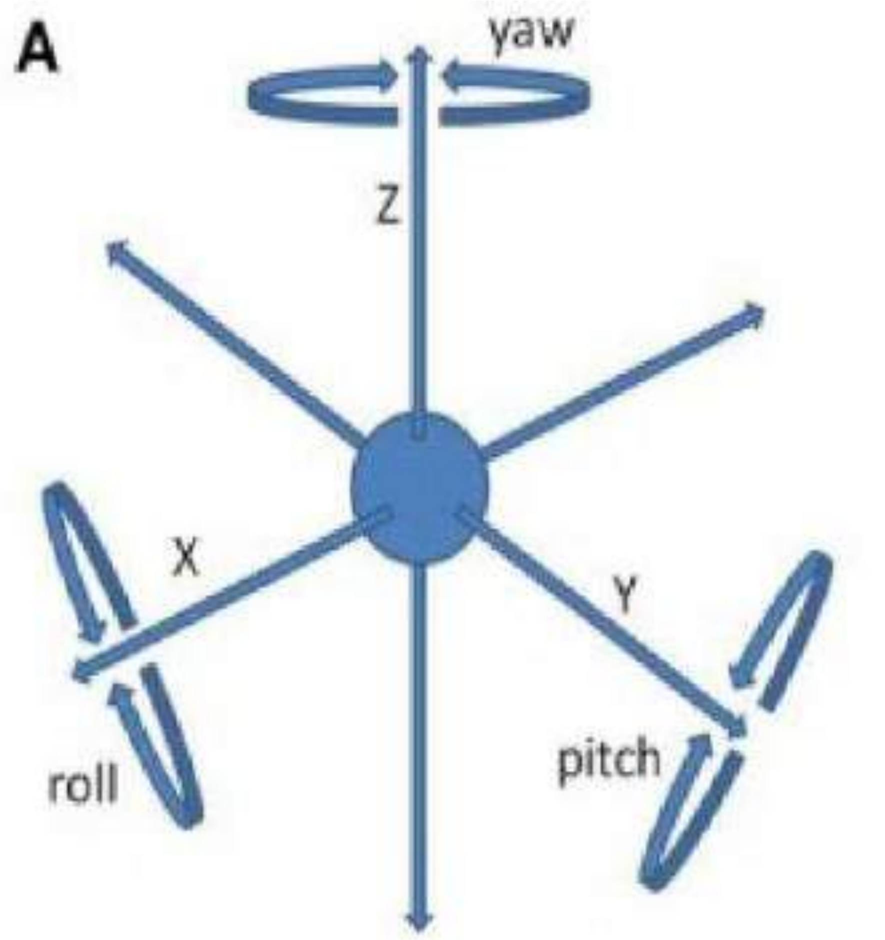
Manipulator

- KUKA KR 240-2 industrial robot
  - 240 kg payload capacity
  - 6 joints allow x,y,z positioning at any θ,ψ,φ angle
  - 2.7 m reach
  - Reproducibility of 0.12 mm!!

Robot

- Allows for 6 degrees of freedom (x, y, z, r, p, w)
  - Non-coplanar beams
  - Compensate for patient movement
- High degree of precision ± 0.06 mm.

6 Degree of freedom



This insure:

- Unconstrained by coplanar treatments
- Can deliver beams from almost any position and angle
- No fixed isocentre – unless you want one

Cyber-linac

- 6 MV X- ray (1.5 cm Dmax)
- Straight wave guide.
- No flattening filter (FFF)
- Up to 1000 cGy/min.
- Sealed ion chamber.
- 800 mm SSD

CyberKnife Collimator Options

1. Fixed Collimator System
2. Iris Variable Aperture
3. Multileaf Collimator (MLC)

Fixed Collimator System

Twelve secondary collimators providing the following field sizes at 800 mm SAD:

- 5 mm
- 7.5 mm
- 10 mm
- 12.5 mm
- 15 mm
- 20 mm
- 25 mm
- 30 mm
- 35 mm
- 40 mm
- 50 mm
- 60 mm

Iris Variable Aperture Collimator

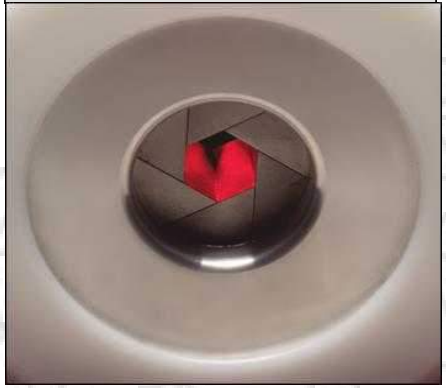
-Tungsten segments rapidly manipulate beam geometry

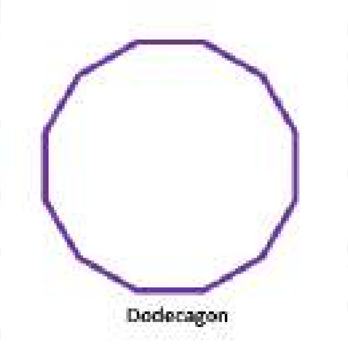
-Two stacked banks of 6 tungsten segments creates 12-sided variable aperture

-Reduces treatment time by dynamically changing multiple aperture sizes in a single path

-Automatically changes size of variable aperture without re-entering treatment suite

-The mechanical accuracy of the Iris aperture is 0.2mm





Multileaf Collimator (MLC)

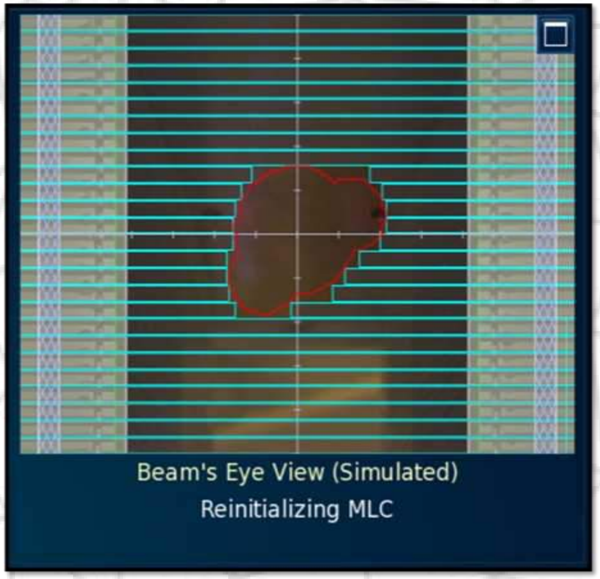
- Maximum clinical field size approximately 115 mm x 100 mm at 800 mm SAD

- Distal plane of leaves to LINAC source distance: 400 mm

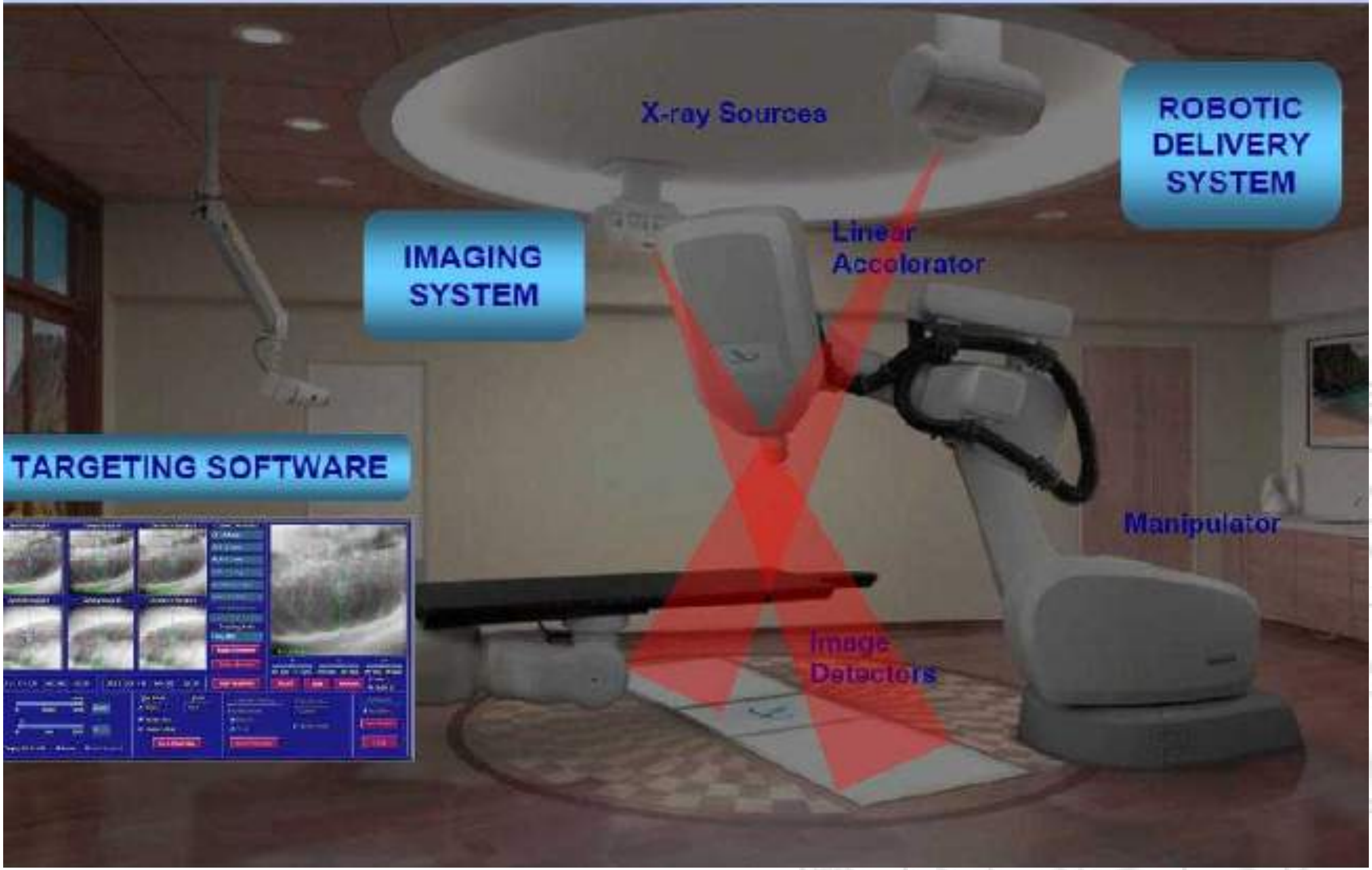
- 2 banks of 26 leaves
  – Minimum 2 leafs open
  – 3.85 mm thickness

- 100% over-travel

- Full inter-digitation



Cyberknife Components



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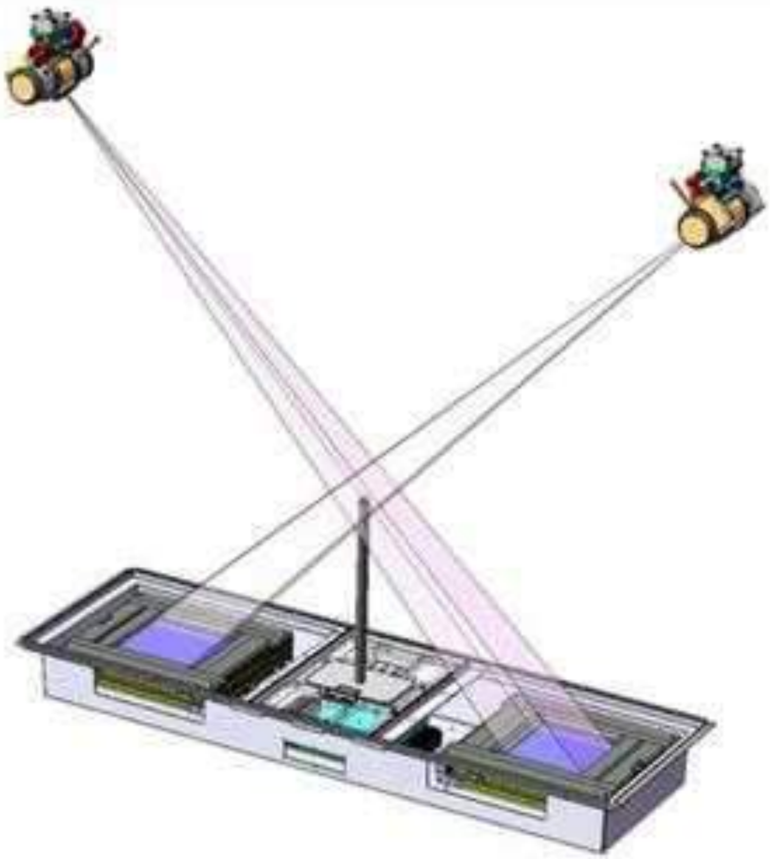
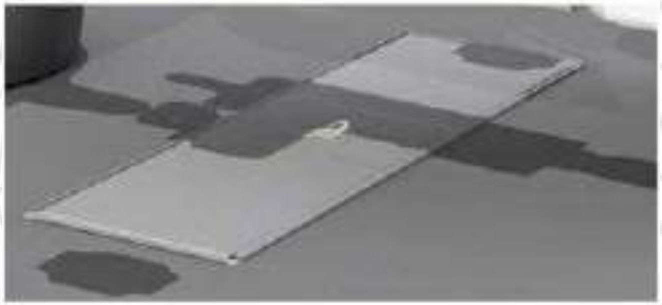
Target Locating System (TLS)



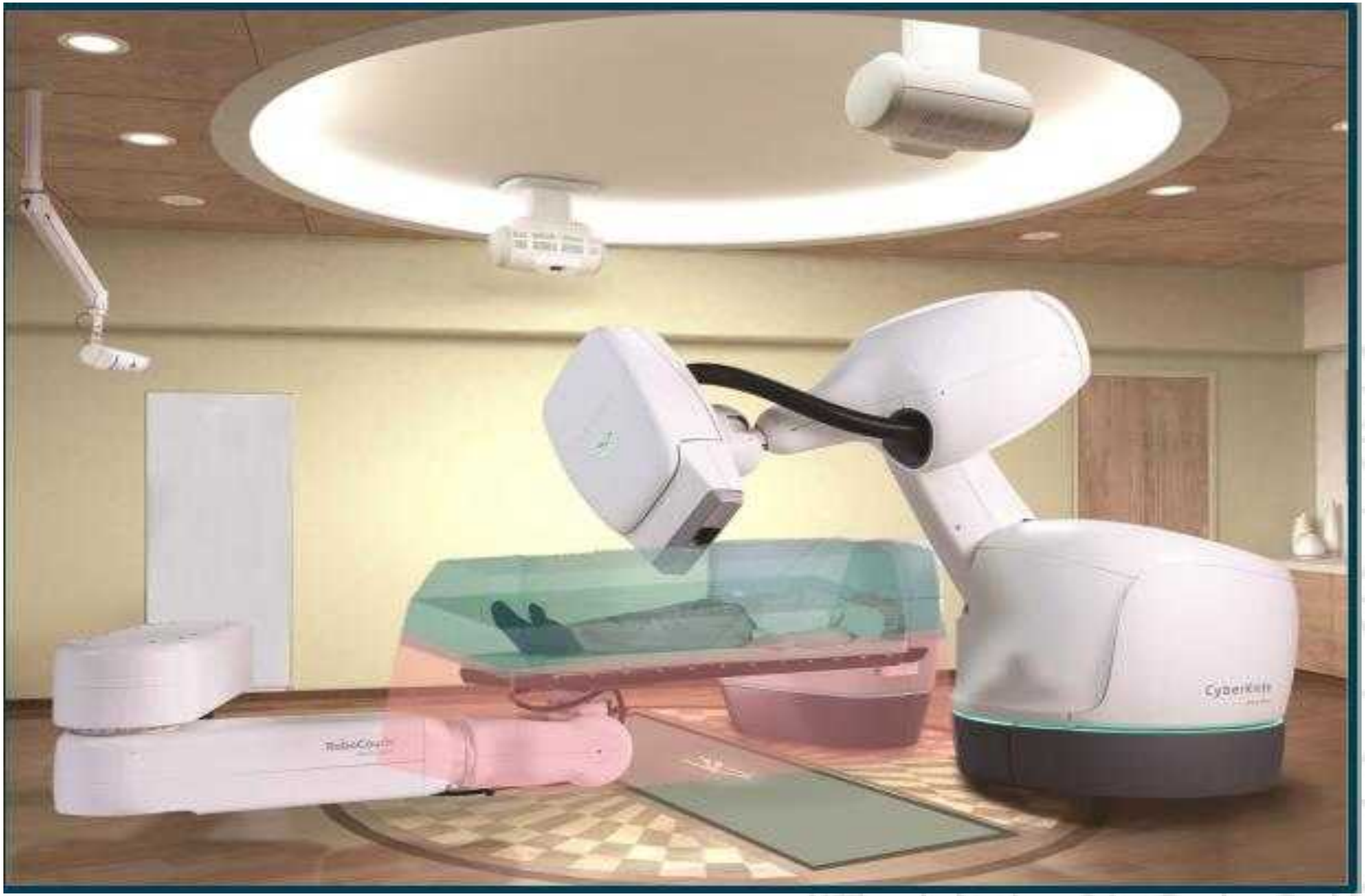
X-ray Sources

X-ray Detectors



Real- time images every 5 -150 sec

Safety Zones

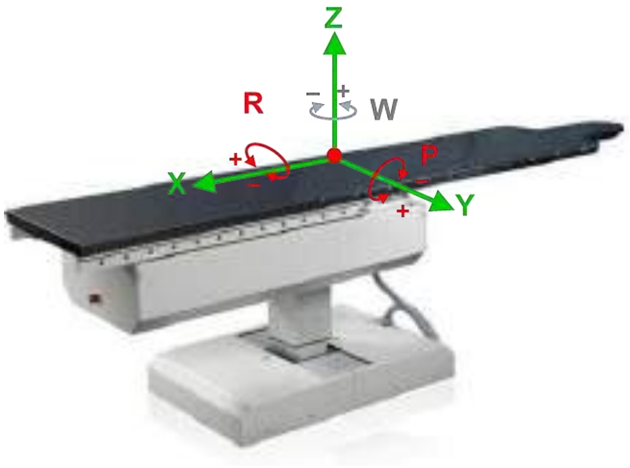


3 Couches

- Standard
- RoboCouch
- Seated Load

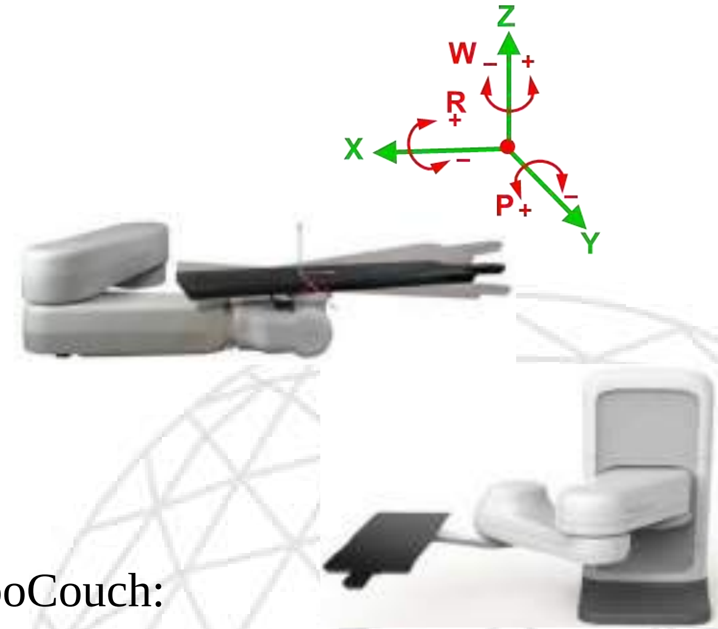
Treatment Couch

®



- Standard Treatment Couch:

  Maximum Patient Load = 159 Kg



- RoboCouch:

  Maximum Patient Load = 227 Kg

X:	+ = Superior,	– = Inferior	R (roll):	+ = Roll Right,	– = Roll Left
Y:	+ = Right,	– = Left	P (pitch):	+ = Head Up,	– = Head Down
Z:	+ = Anterior,	– = Posterior	W (yaw):	+ = Clockwise,	– = Counterclockwise (manual)

Seated Load

- Adds 7th joint and knee-up position
- 16 inch load
- 227 kg limit

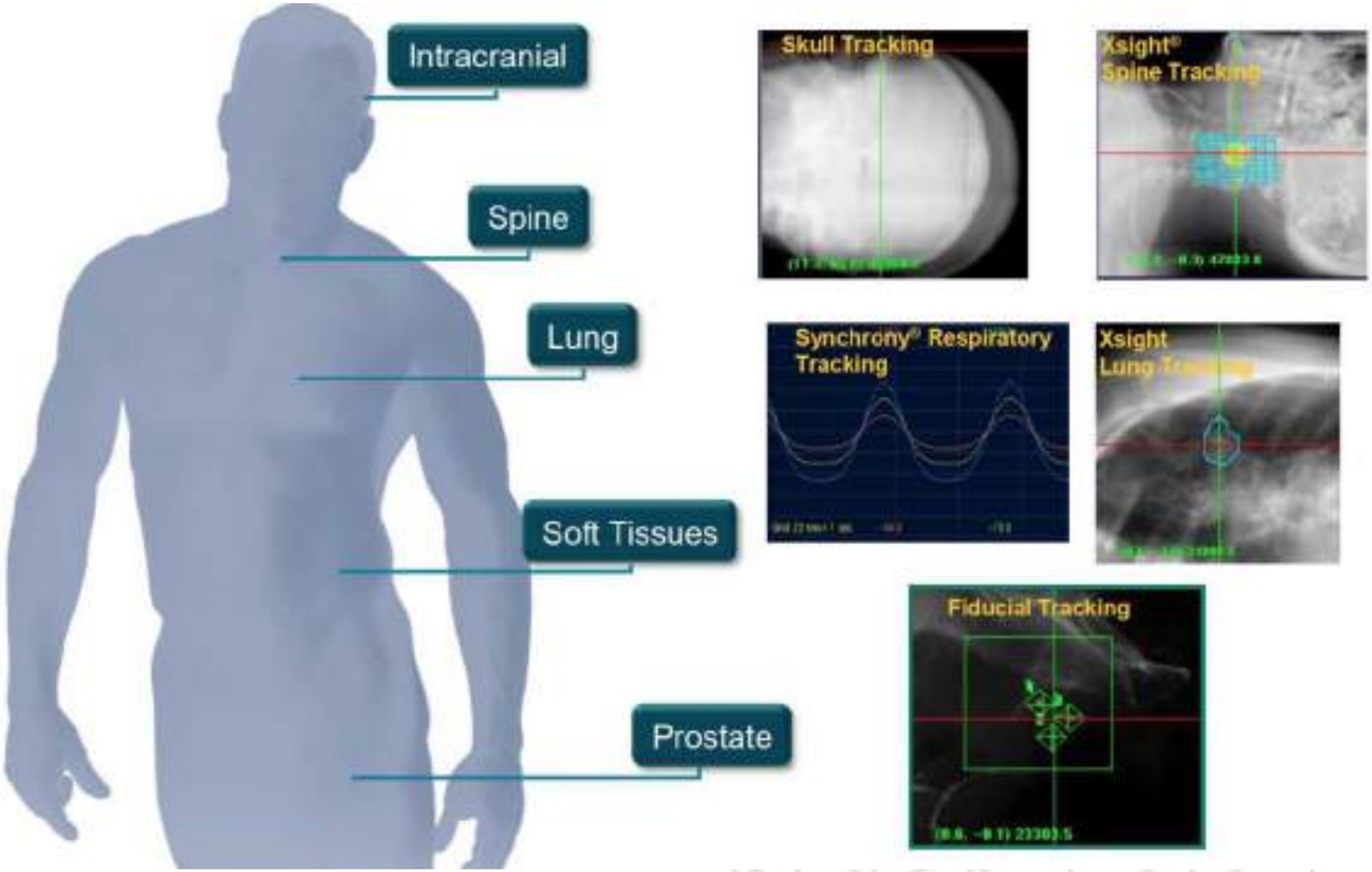
How is the technology different?

- Advanced interactive robotics (Linac & Couch).
- Real-time imaging.
- Dynamic automated motion tracking.
- Flexible and accurate linac multiple-beam radiation delivery.
- Robotic couch for more automated and accurate radiation dose delivery.

Tracking Types

- Skull Tracking
- XSight Spine
- Xsight Lung
- Fiducials
- Synchrony

Tracking algorithms



Methods for tracking motion

- Skull tracking: bony landmarks are 6 D tracking
- spine tracking: bony landmarks are tracked
- Fiducial tracking: radio-opaque marker are placed near soft tissue targets and tracked
- Respiratory tracking (Synchrony): with respiration, LED's on the exterior of the patient are correlated with the movement of the target/tumor and fiducials

6D skull tracking

The 6D Skull Tracking feature in the CyberKnife System allows direct and non-invasive tracking of intracranial lesions.

Target tracking and motion compensation are accomplished by identifying and tracking rigid skull anatomy by using image intensity and brightness gradients between the DRR and live images.

Patient setup, alignment and lesion tracking is done non-invasively and without the use of rigid head mounted frames.

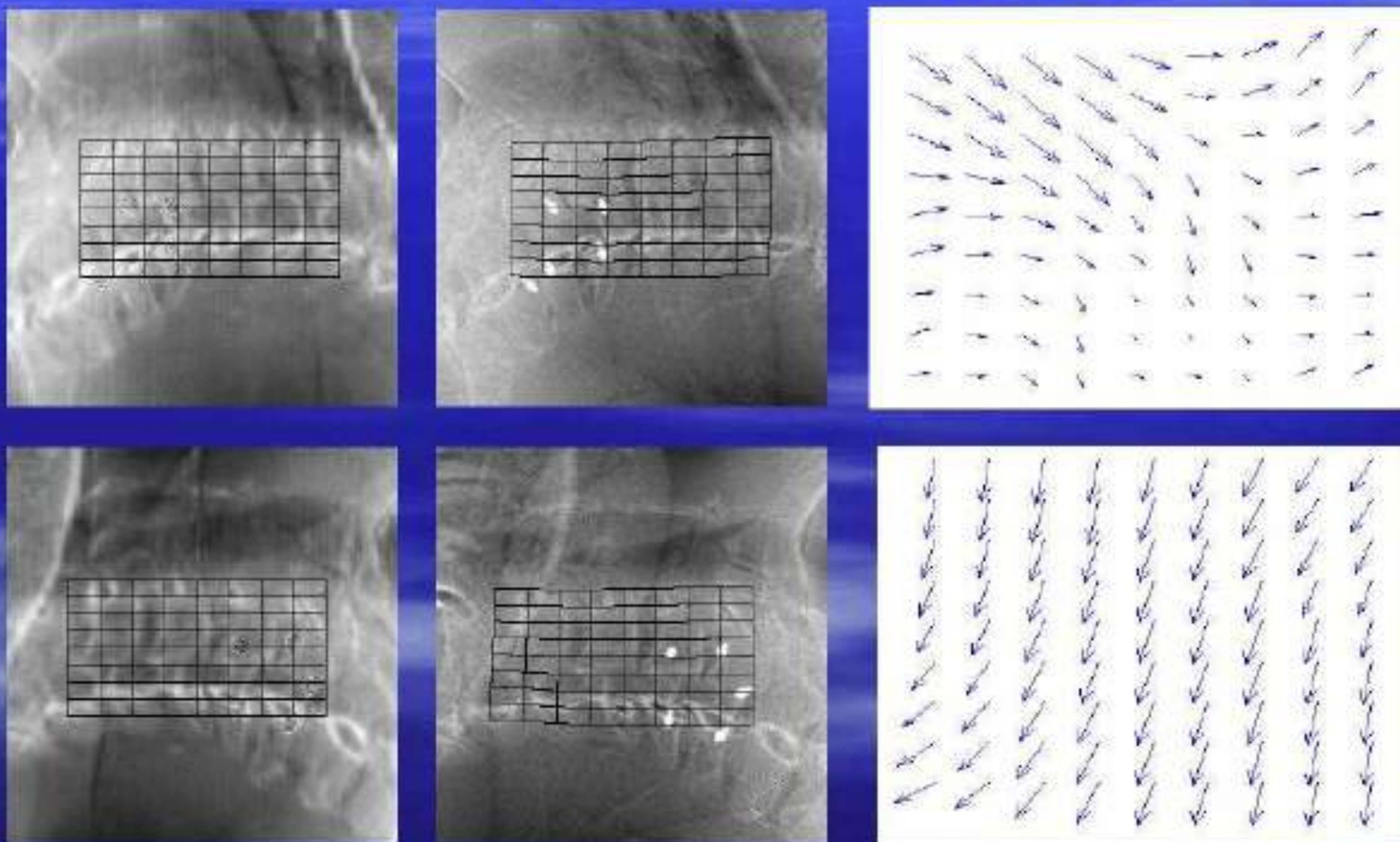
This method is referred to as 6D because corrections are made for the 3 translational motions (X,Y and Z) and three rotational motions.

XSight Spine - How it works…

DRR (from CT) | Live kV image | Displacement Field

Image A

Image B



Xsight Spine Tracking System

The Xsight Spine Tracking System enables the tracking of skeletal structures in the cervical, thoracic, lumbar and sacral regions of the

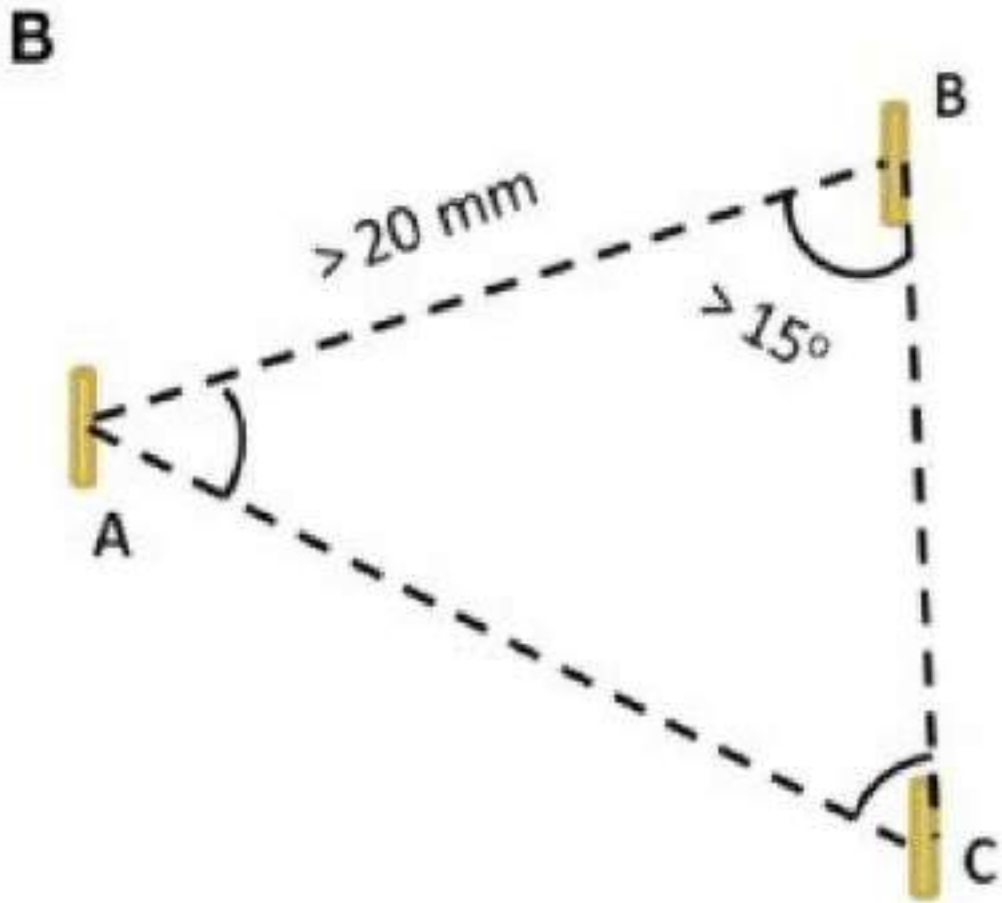
spine for accurate patient positioning and radiation beam deliver using the CyberKnife System without implanting fiducials.

Target tracking with the Xsight Spine System is accomplished using 2D registrations on a mesh where local displacements at

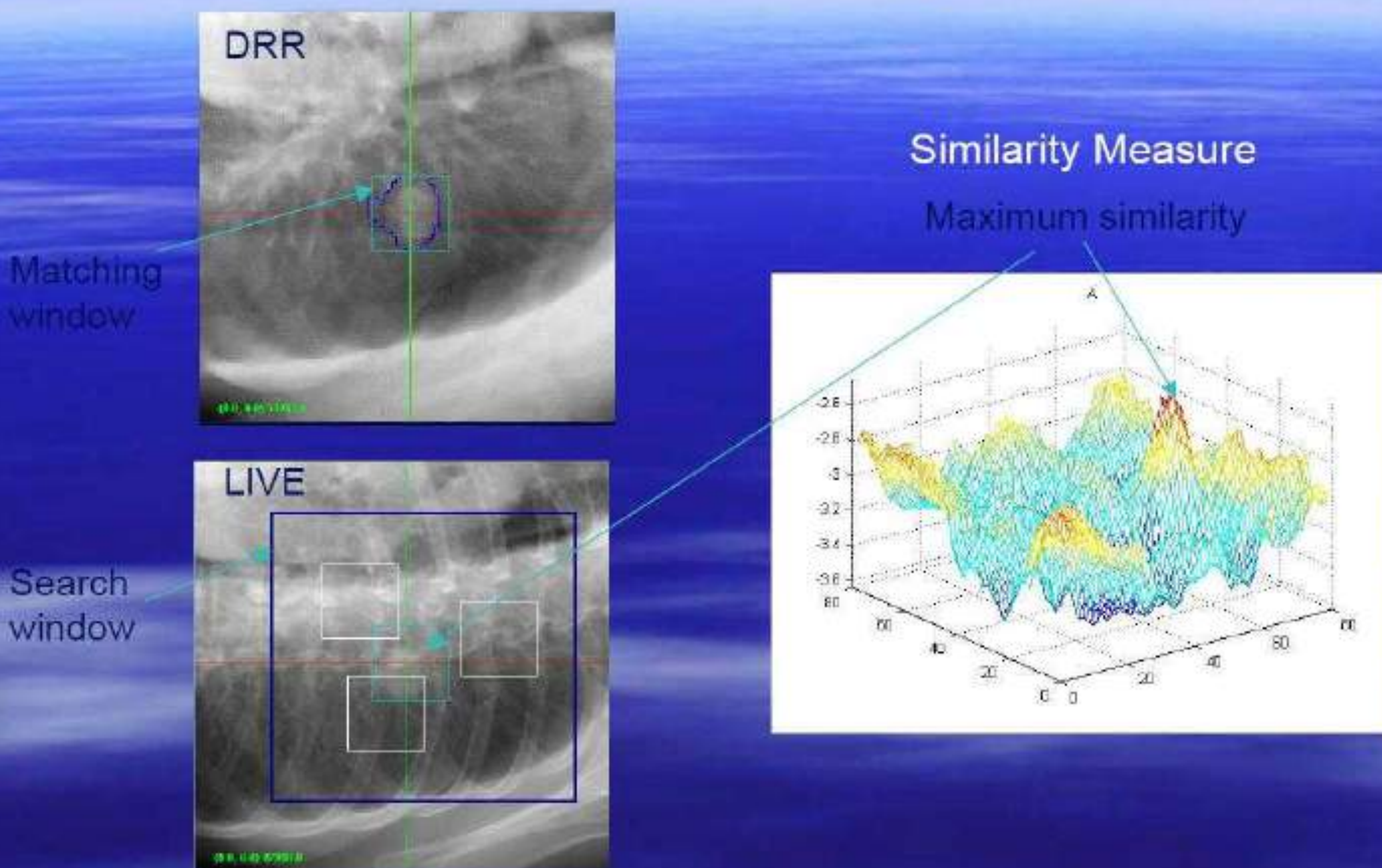
FIDUCIAL TRACKING

- The fiducial tracking system enables tracking extracranial tumors by tracking implanted fiducial markers. Fiducial traking mode correlates fiducial location in reference DRR images with live x-ray images to extract fiducial location.Fiducial tracking mode allow tracking and treating tumours.

The parameter rigid body distance threshold in this system will give the maximum deviation of the fiducial between DRR and the x ray image


B
B
>20 mm
>15°
A
C

XSight Lung


DRR
Matching window
LIVE
Search window
Similarity Measure
Maximum similarity
A
-2.6
-2.8
-3
-3.2
-3.4
-3.6
80
60
40
20
0

Synchrony Tracking

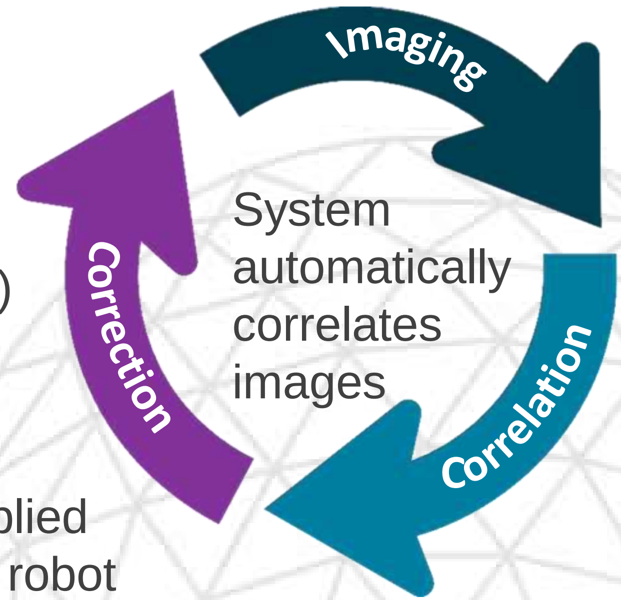
The Synchrony Respiratory Tracking System continuously synchronizes treatment beam delivery to the motion of a target that is moving with respiration.

The system operates by creating a correlation model between thepatient's breathing pattern, monitored in real-time, and the location of thetarget at various points in the respiration cycle.

The location of the target is determined by using X-ray imaging to visualize the lesion or internal markers (fiducials), while the breathing pattern is tracked and monitored using external markers (LED-based, fiber optic tracking markers) in real-time.

CyberKnife System Treatment Automation

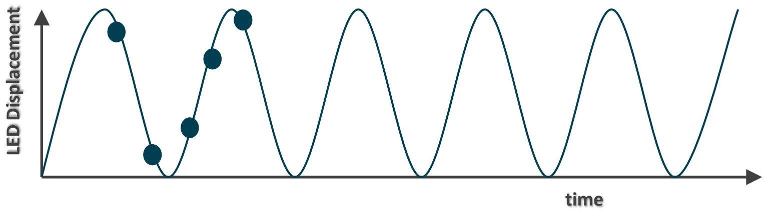
Images taken at user-set interval (5-150 seconds)



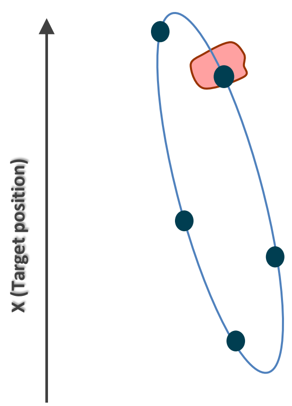
System automatically correlates images

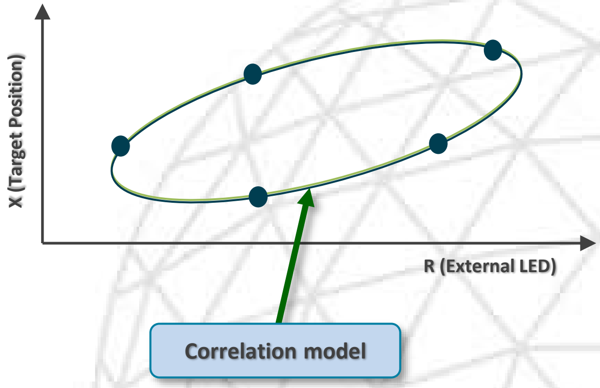
- Values applied directly by robot
- System always corrects for residual offsets

How it works: model generation



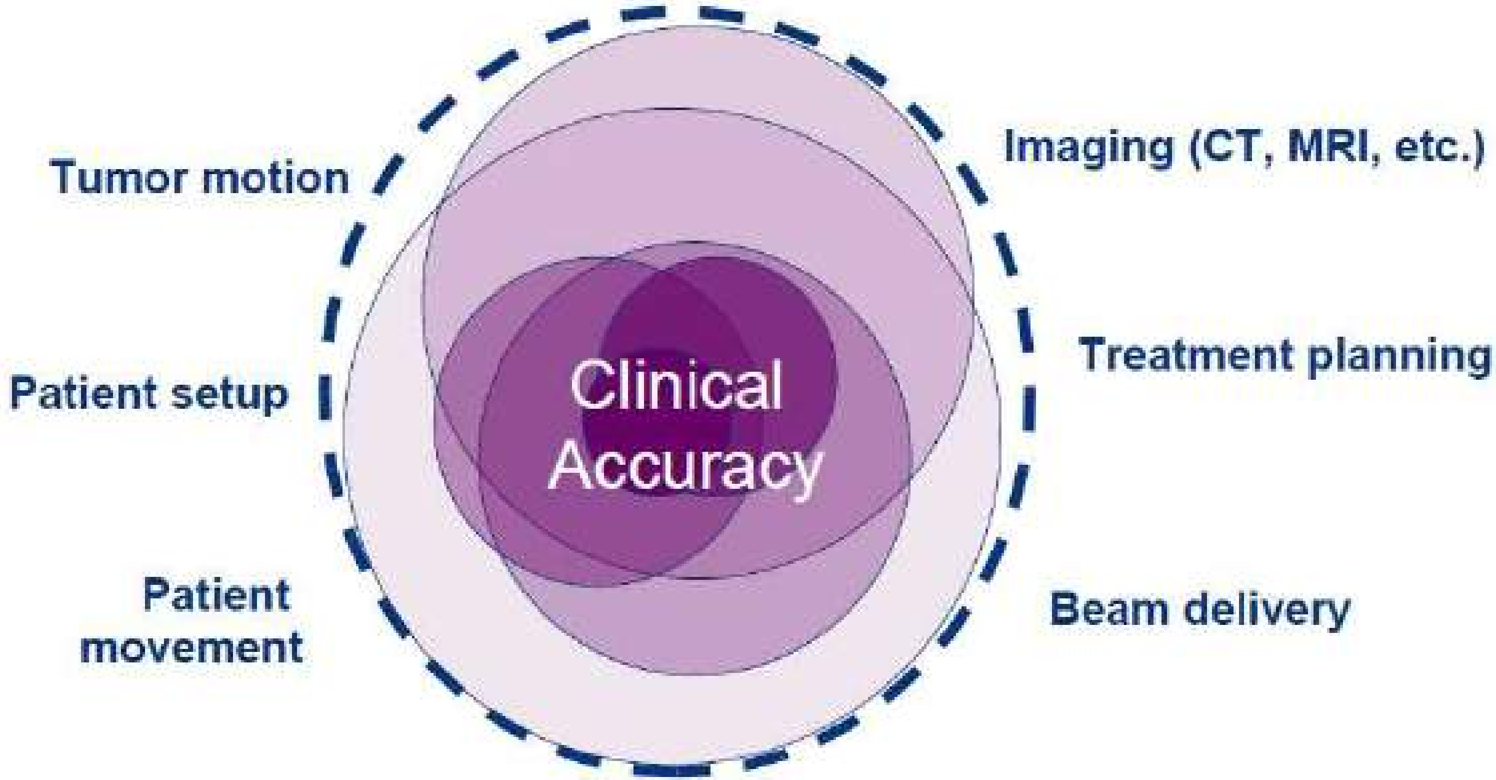
Model creation





Defining Accuracy

- Traditional Definition: Mechanical Accuracy
- New Definition: Clinical Accuracy



Targeting Accuracy Using Synchrony

Moving Lesions

- Dieterich, S, et al. The CyberKnife Synchrony™ Respiratory Tracking System: Evaluation of Systematic Targeting Uncertainty
  - Objective: Quantify systematic geometric uncertainties in treatment delivery using Synchrony for range of simulated respiratory motions
  - Methodology: Accuracy measured at Georgetown University Hospital, Boulder Community Hospital, UCSF

	Site 1	*Site 2*	*Site 3*	*Mean*	*SD*
0 deg	1.05	0.62	0.46	0.71	0.31
15 deg	1.05	0.74	0.11	0.63	0.48
30 deg	1.08	0.55	0.64	0.76	0.28

- **Results: Mean systematic error of 0.70 ± 0.33 mm**
- Synchrony accuracy specification: 1.5 mm

Indications for Cyberknife

- **Intracranial lesions**: single fraction, or fractionated
- **Head and neck**:
  - Nasopharynx & base of skull, primary or recurrent
  - Other sites, as boost following conventional RT, or recurrent
- **Spine**: where surgery indicated but not feasible, and conventional RT less effective or not possible
- **Lung**: where surgery indicated but not feasible
- **Liver**: where surgery indicated but not feasible
- **Pancreas**: unresectable but localized tumors
- **Kidney**: where surgery indicated but not feasible
- **Previously irradiated tumors**

Clinical Benefits

- Staged/Fractionated Radiosurgery
  - 1-5 fractions/stages
  - Larger lesions
  - Lesions next to critical structures/organs at risk
- Improved Patient Quality of Life
  - Short treatment course: 1-5 days CyberKnife vs. 6-8 wks Radiotherapy
    - Optimal for patients
    - Optimal for patients with limited life expectancy
    - Increased convenience
  - No infection risk
  - No general anesthesia
  - Minimal to no recovery time, as compared to open surgery

Cyberknife Vs Gamma-Knife: Dissimilarity

	GK	CK	Comments
Immobilization device	Rigid frame	Orfit	CK has favorable orfit
RT source	Co60	6MV LA	GK need to replace sources every 5/6 yrs
Planning	No complex planning	Inverse planning	Favorable dosimetry in CK
Planning method	Simple	Complex	Even neurosurgeons can plan in GK
Isodose pres	Usually 50%	Usually 80-95%	GK: more dose heterogeniety
Fractions	Single	May treat multiple fraction	Radiobiology favorable in CK
Tumour size	Only smaller lesions can be treated	Larger lesions also can be treated in fractionated schedule	Increased indications with CK
Energy source	Radiation	Electricity	GK can work with less electricity
Verification	Not possible	Possible	Even Intra-fraction movement can be corrected
Indications	Only brain lesions	Extra & intra cranial	CK more economical

Limitations of Cyberknife

- No posterior (under couch) shooting.
- More complex planning
- Long treatment time.
- Significant QA required prior to treatment to ensure that the robotic arm acts as expected.

Thank you