



# Cyberknife

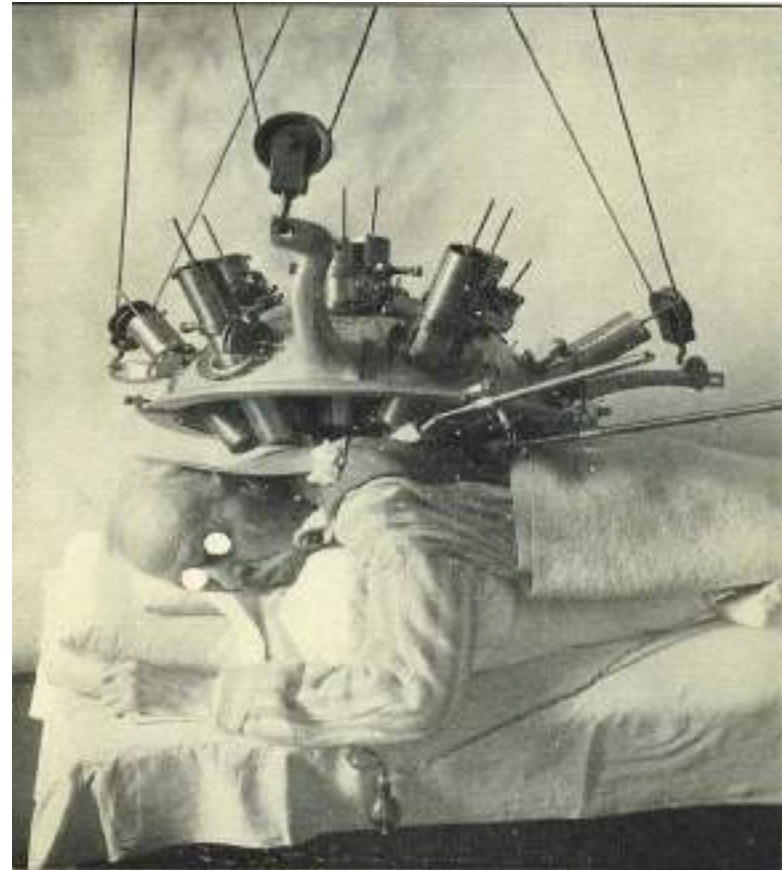
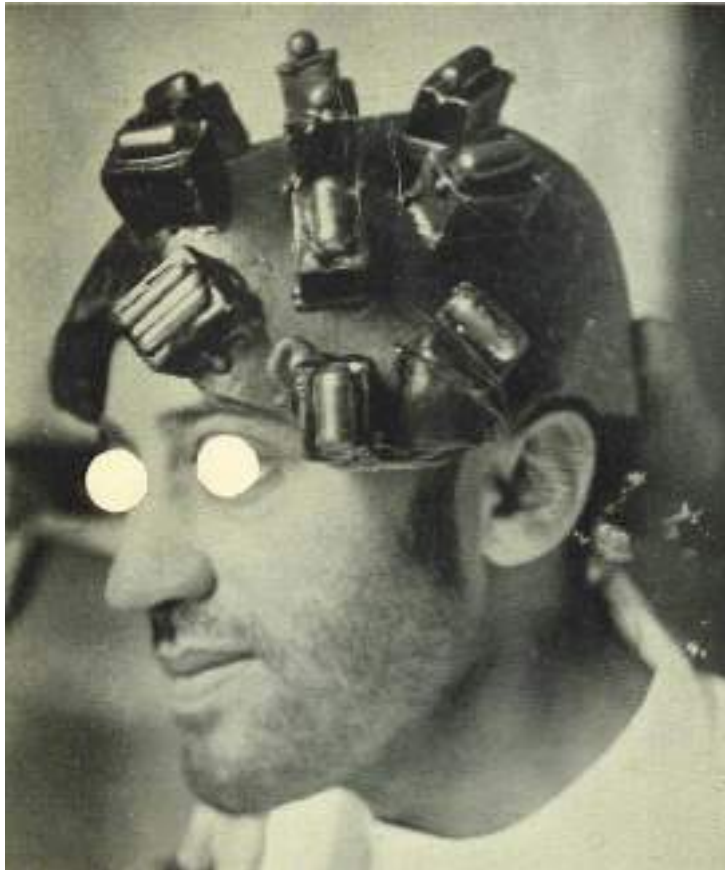
**Mohamed S, Zaghloul, MD**  
**National Cancer Institute, Cairo University**  
**Chairman, Radiation Oncology Department,**  
**Children's Cancer Hospital, Egypt.**



- Disclosure:  
I have no disclosure to declare.



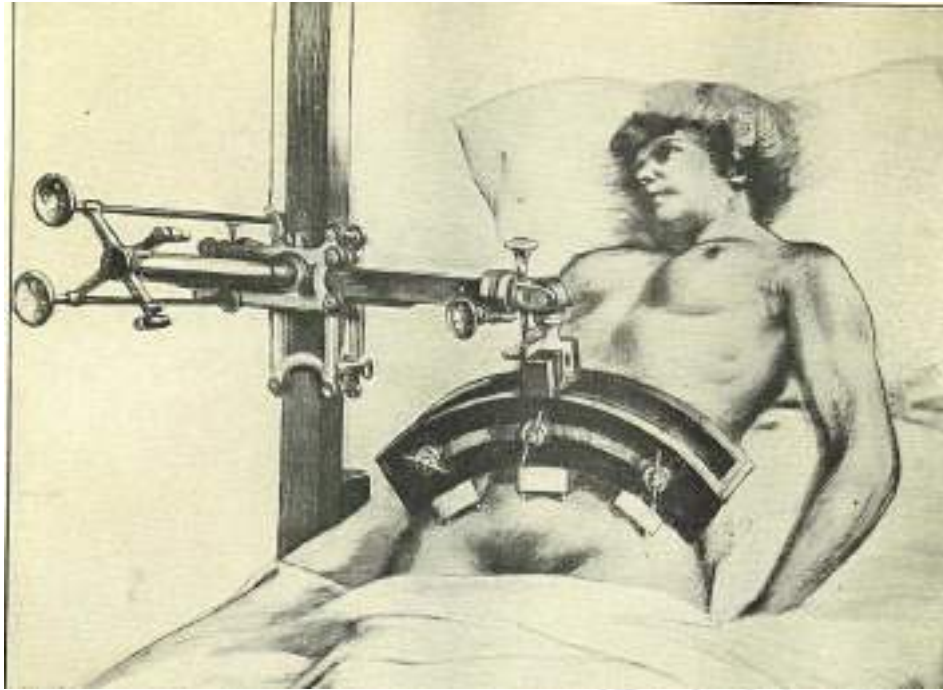
## Radium Bomb (Kasr El Ainy in the 1930's)



Zaghloul & Bishr Int J Radiat Oncol Biol Phys, 2018



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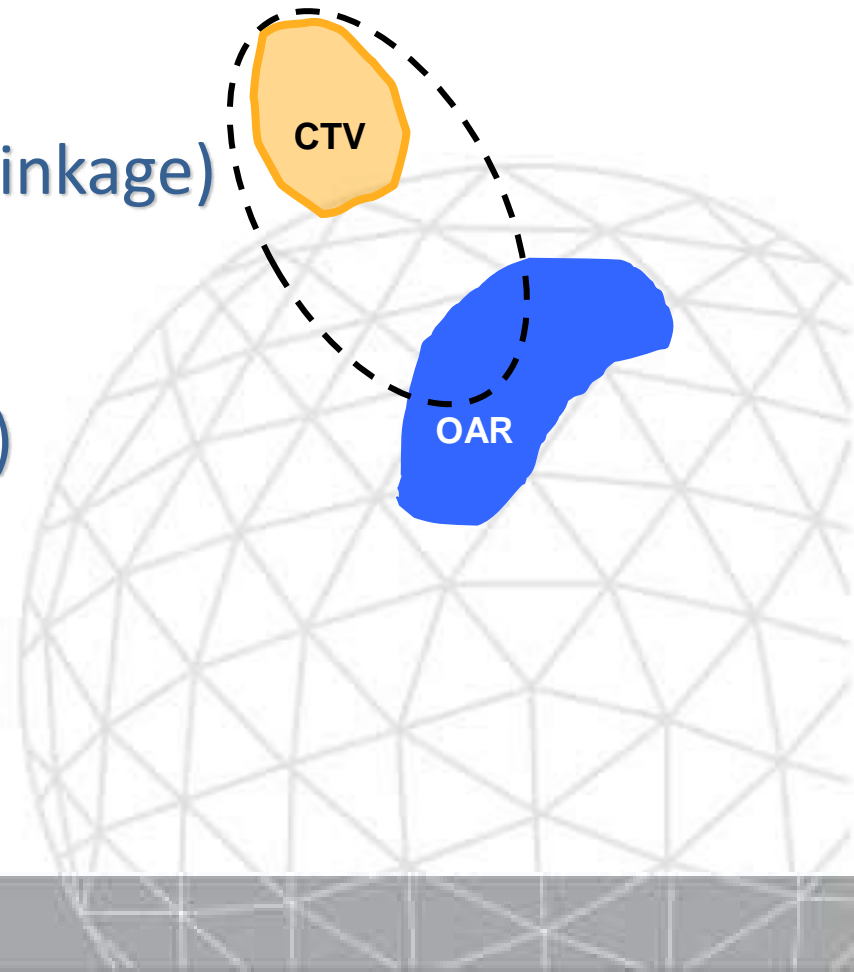
# External Beam Irradiation





## 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 Stereotactic frame(1946)



Henry Wycis

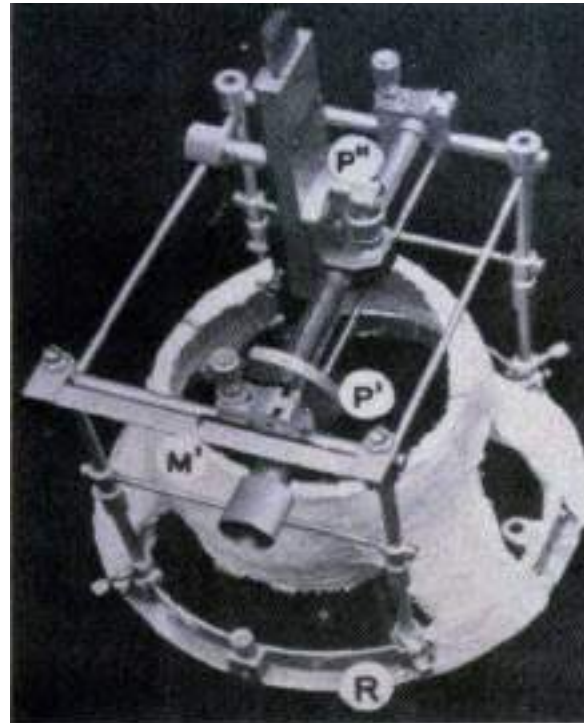


Figure 1.2. Spiegel and Wycis' original human stereotactic frame.



Ernest Spiegel

**First Human Stereotactic frame 1946**



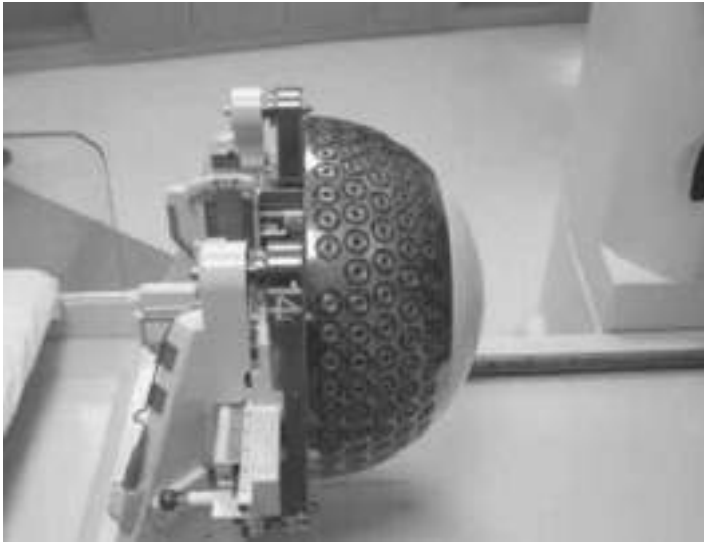
# Laksel invented the Gammaknife (1958)



Lars Leksell



# First Gamma Knife (1968)



- 1968, **SophiahemmetHospiatl** in **Stockholm , Sweden.**
- 197 sources CO-60



# Linac Radiosurgery (1988)

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Vol. 11, No. 2, 1988  
Printed in U.S.A.

## Linear Accelerator as a Neurosurgical Tool for Stereotactic Radiosurgery

Ken K. Witton, M.D., and Wendell Lott, Ph.D.

Department of Neurosurgery of The Children's Hospital, Department of Surgery (Neurosurgery) of the Brigham and Women's Hospital, The Adult Center for Radiation Therapy, and Harvard Medical School, Boston, Massachusetts

A new system has been developed for stereotactically delivering prescribed high doses of radiation to precisely located volumes of approx. 0.8 to 1.0 cc within the brain. A Brown-Berens-Wolf's stereotactic apparatus and a 6-MeV linear accelerator equipped with a special collimator (12.5 to 35 mm in diameter) have been adapted. The 35-mm collimator allows treatment of a nearly spherical volume of 2.3 cc. Outside the treatment field, the dosage declines to 80% of the dose prescribed for the periphery of the lesion over a distance of 1.8 cm, and to 50% over the next 3.4 cm. Localization can be accomplished via computer tomography or cerebral angiography. Treatment is accomplished with an x-ray beam of photon radiation with the treatment couch in each of four positions. The entire system has been extensively tested for accuracy in alignment and distribution of radiation. Series have been presented for the alignment of the apparatus and for the criteria of localization. Safety of operation was emphasized throughout the design and testing phase. (Neurosurgery) 22:444-464, 1988.

**Key words:** Computerized tomography-guided radiosurgery. Linear accelerator. Stereotactic radiosurgery. Stereotaxis.

Stereotactic radiosurgery, the idea, a method, and even the term were published by Leksell in 1951 (1). He initially used the stereotactic frame that he had described 2 years earlier and a special collimator attached to an x-ray tube. The collimator could be moved along a track that circumscribed an arc over the head, thereby casting the x-ray beam at a particular and localized point in the brain. Later Leksell accomplished the same with a gamma knife (14, 15, 16) and, in 1966, he began to use an array of cobalt-60 sources to produce disc-shaped lesions for functional neurosurgery and to treat certain tumors and arteriovenous malformations (17). The system has been extensively modified and improved since that early report (15). Other systems of stereotactic radiosurgery have been in use in the United States and in the Soviet Union for many years, particularly the types of craniom and before from stereotacticones (8, 9, 10, 21).

Neurosurgical radiosurgery is an extremely accurate procedure

"nose" is known, not "front" the matrix of tissue containing the lesion. With respect to therapeutic principles, stereotactic radiosurgery has little in common with radiation therapy. In stereotactic radiosurgery, a high dose of radiation is delivered, usually in a single fraction, to a precisely defined target volume of tissue, the lesion, while the extension and rest tissues are distributed so that tissue outside the lesion is minimally irradiated. There is no attempt to generate "good" cells within the lesion by taking advantage of a differential biological sensitivity to radiation, which is a basic principle of conventional radiation therapy.

The Swedish system is a dedicated unit costing several million dollars and, although simple to operate, its alignment and precision cannot be easily verified and the tube (600 mm) is replaced at least every 10 years. Medical cyclotrons exist in only a few places, are extremely complex, and are costly to operate; a very one of the basic necessary to produce the standard radiation dose (approximately 2000 rads) over the volume of

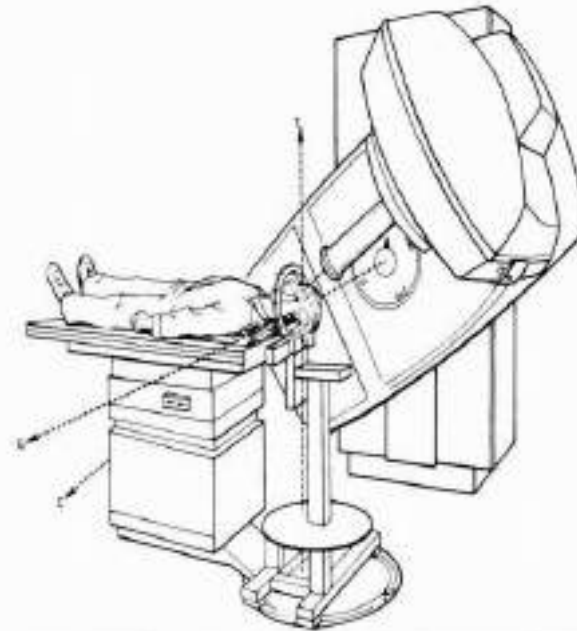
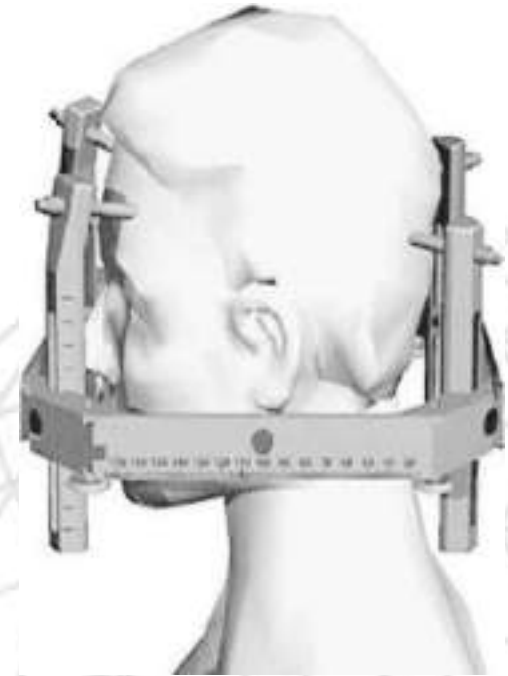


Fig. 1. Linear accelerator with 35-mm filter used mounted to plate overlying the bearing that supports the turntable treatment couch. The collimator approaches within a few centimeters of the patient's head. Dotted lines indicate axis of rotation of the gantry (G), the turntable (T), and the collimator (C). These three axes intersect at the center of the patient's head (see text).

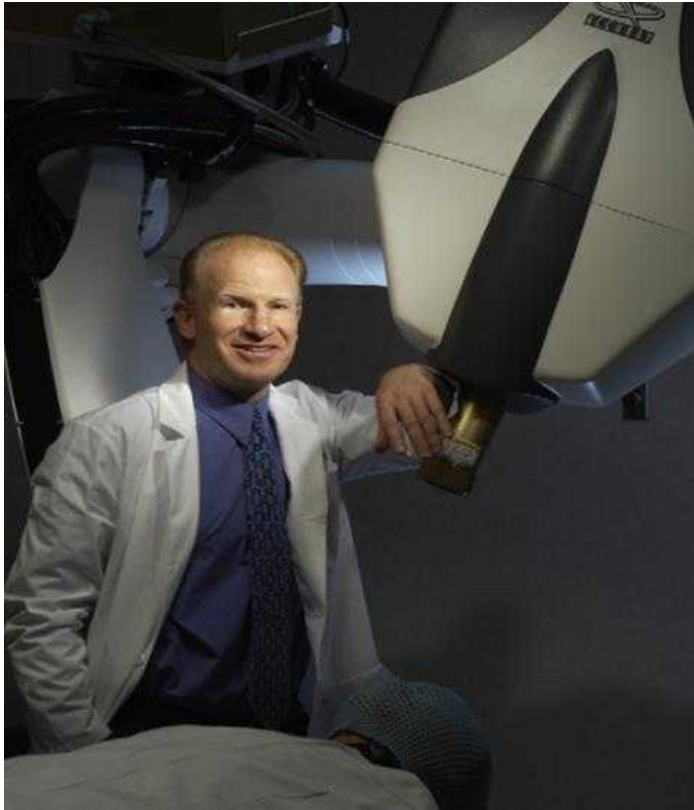


# Linac Invasive Frame





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



# 1<sup>st</sup> delivery at Stanford





# First Patient: June 6, 1994 (Stanford University)

## Radiotherapy

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

**Stereotactic  
- Functional  
Neurosurgery**

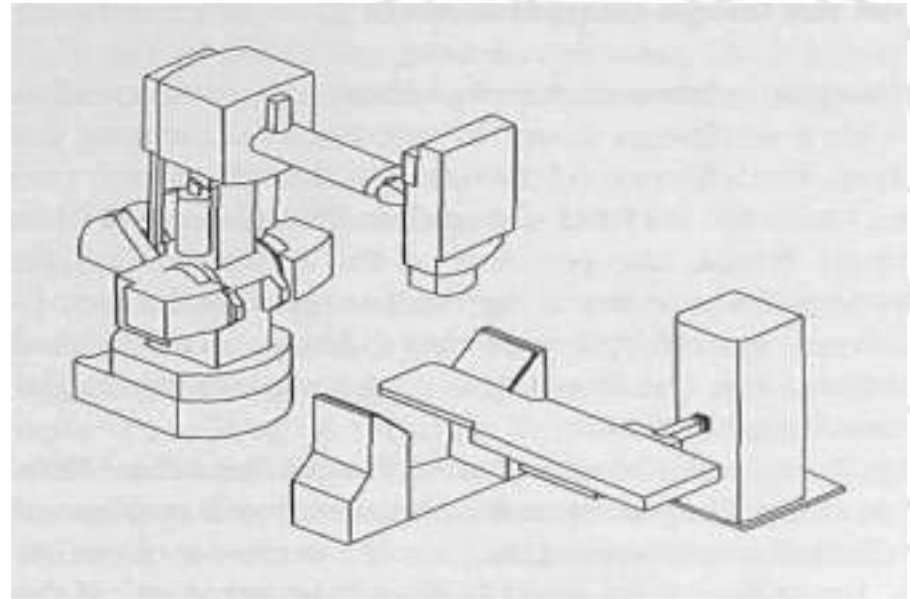
## The Cyberknife: A Frameless Robotic System for Radiotherapy

*John R. Adler, Jr.<sup>a,b</sup>, Steven D. Chang<sup>a</sup>, Martin J. Murphy<sup>b</sup>, James Doty<sup>a,c</sup>,  
Paul Geis<sup>b</sup>, Stephen L. Hancock<sup>b</sup>*

Departments of  
<sup>a</sup> Neurosurgery and

<sup>b</sup> Radiation Oncology, Stanford University Medical Center, Stanford, Calif., and

<sup>c</sup> Newport Radiotherapy 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



6D Skull Tracking



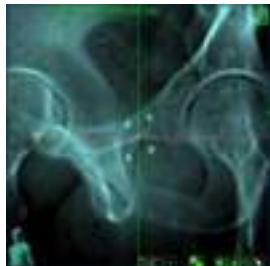
Xsight® Spine Tracking



Xsight Lung Tracking



Synchrony® Respiratory Tracking

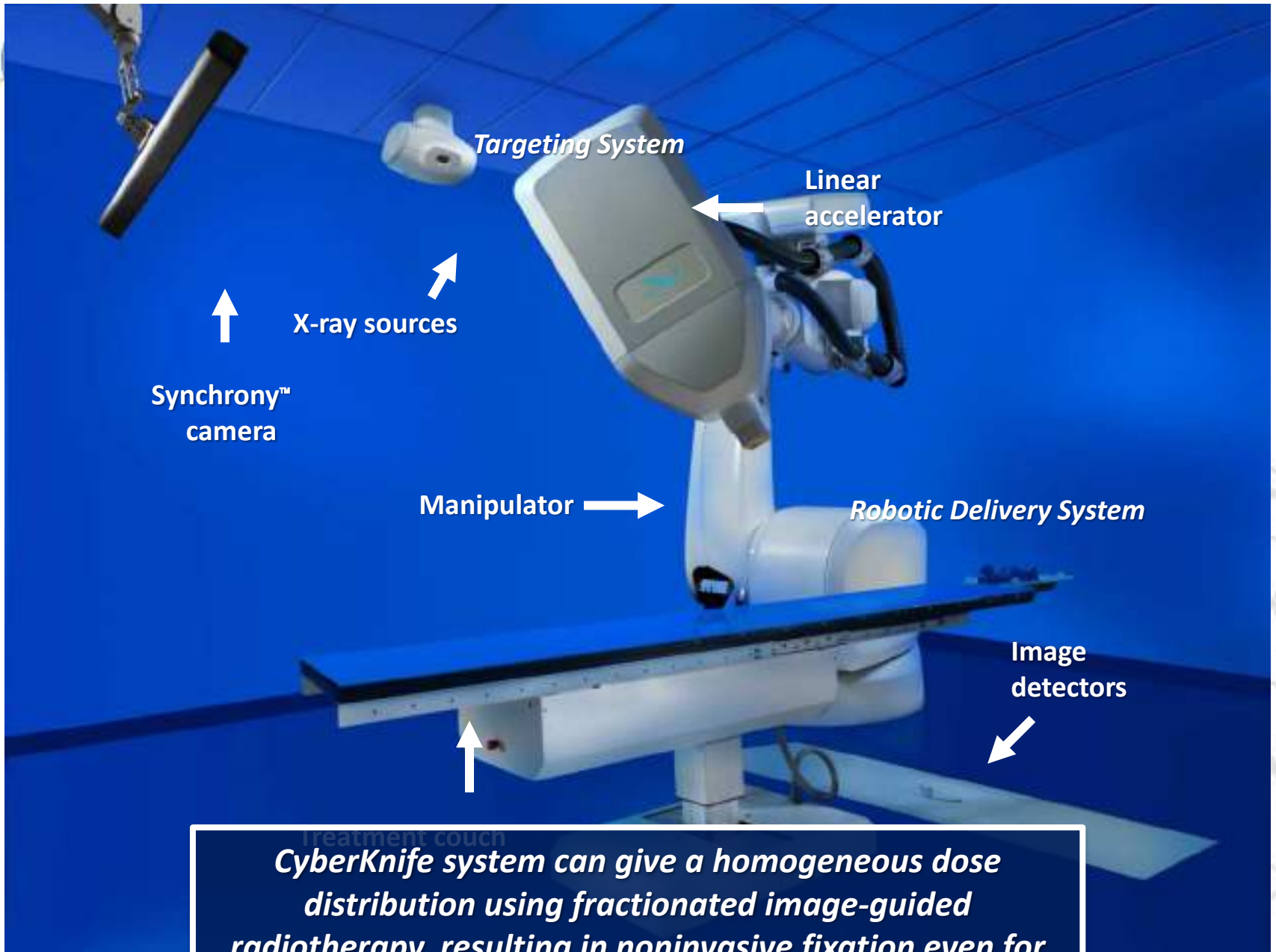


Fiducial Tracking

## THE CYBERKNIFE® SYSTEM CLINICAL APPLICATIONS

- Intracranial**  
Brain metastases, primary tumors, trigeminal neuralgia, arteriovenous malformations (AVMs)
- Head & Neck**  
Primary tumors, re-irradiation, lymph
- Lung**  
Early stage and advanced primary lung cancer, pulmonary metastases
- Liver**  
Liver metastases, inoperable primary liver cancer
- Pancreas**  
Inoperable patients, food pre- or post-surgery
- Spine**  
Spinal metastases, benign tumors, spinal AVMs
- Prostate**  
Low and intermediate risk prostate cancer, non-therapy





*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  $\theta, \psi, \phi$  angle
  - 2.7 m reach
  - Reproducibility of 0.12 mm!!





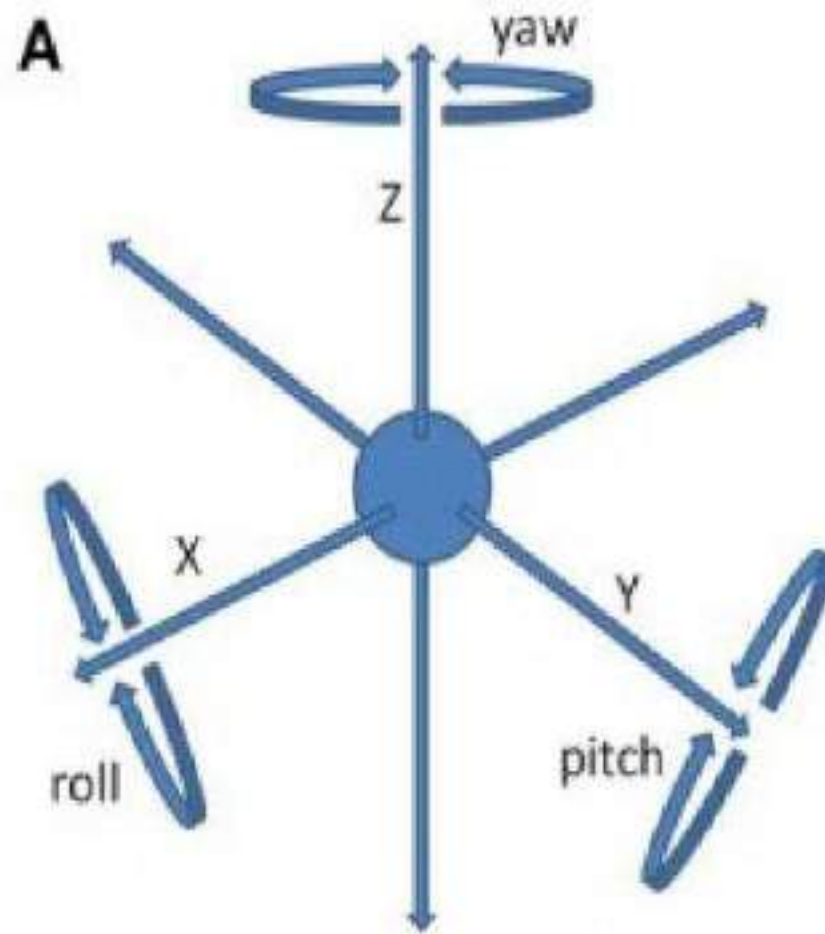
# Robot

- Allows for 6 degrees of freedom (x, y, z, r, p, w)
  - Non-coplanar beams
  - Compensate for patient movement
- High degree of precision  $\pm 0.06$  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:

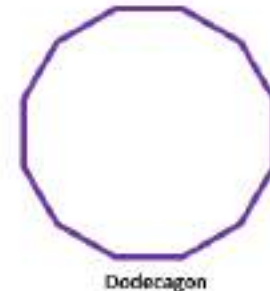
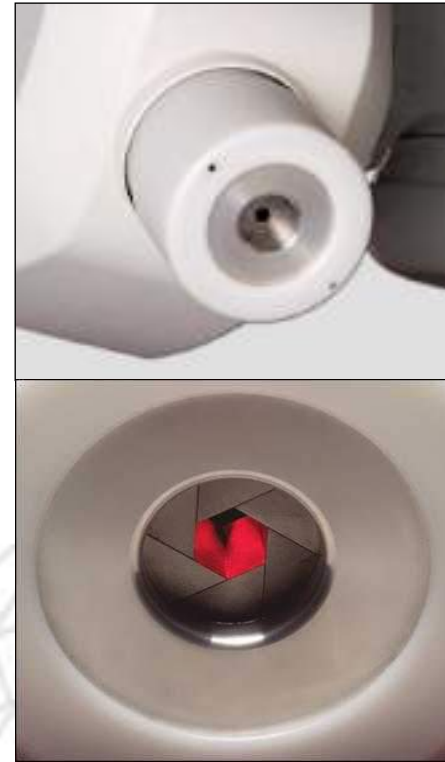
- 5 mm
- 7.5 mm
- 10 mm
- 12.5 mm
- 15 mm
- 20 mm
- 25 mm
- 30 mm
- 35 mm
- 40 mm
- 50 mm
- 60 mm





# Iris Variable Aperture Collimator

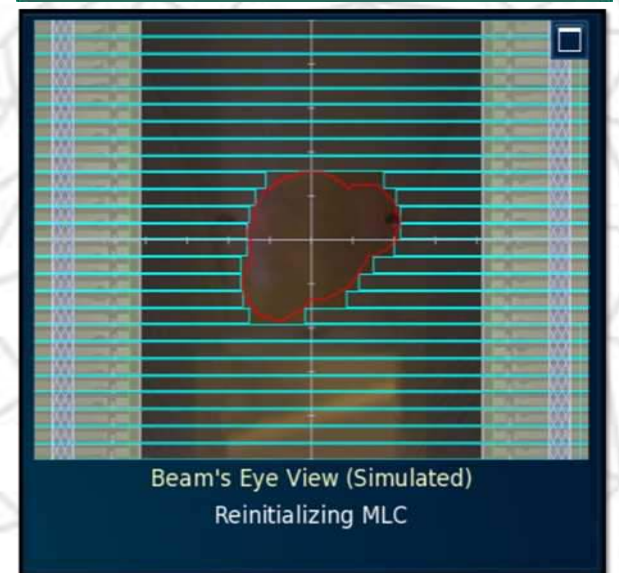
- Tungsten segments rapidly manipulate beam geometry
- Two stacked banks of 6 tungsten segments creates 12-sided variable aperture
- Reduces treatment time by dynamically changing multiple aperture sizes in a single path
- Automatically changes size of variable aperture without re-entering treatment suite
- The mechanical accuracy of the Iris aperture is 0.2mm



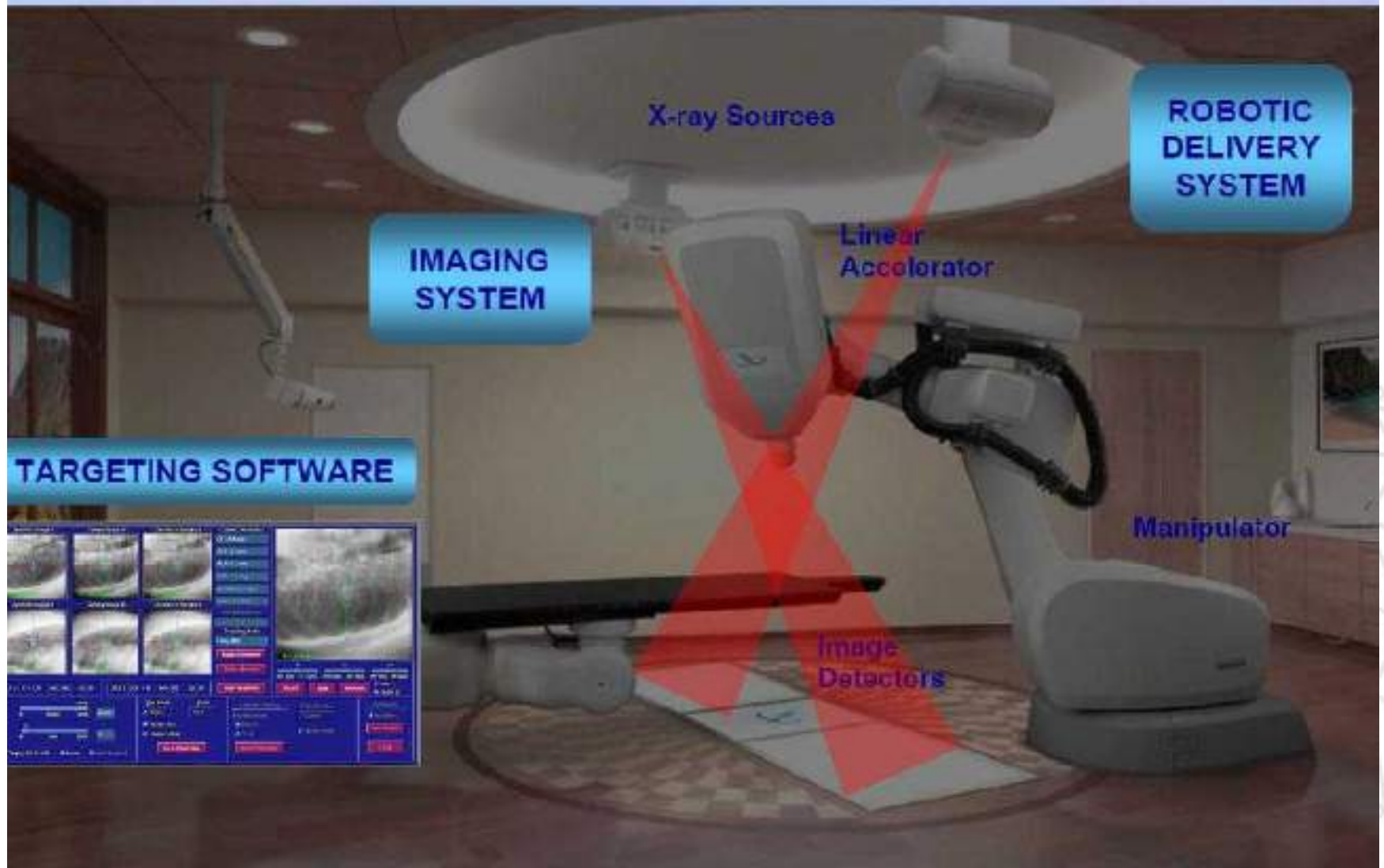


# Multileaf Collimator (MLC)

- **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**

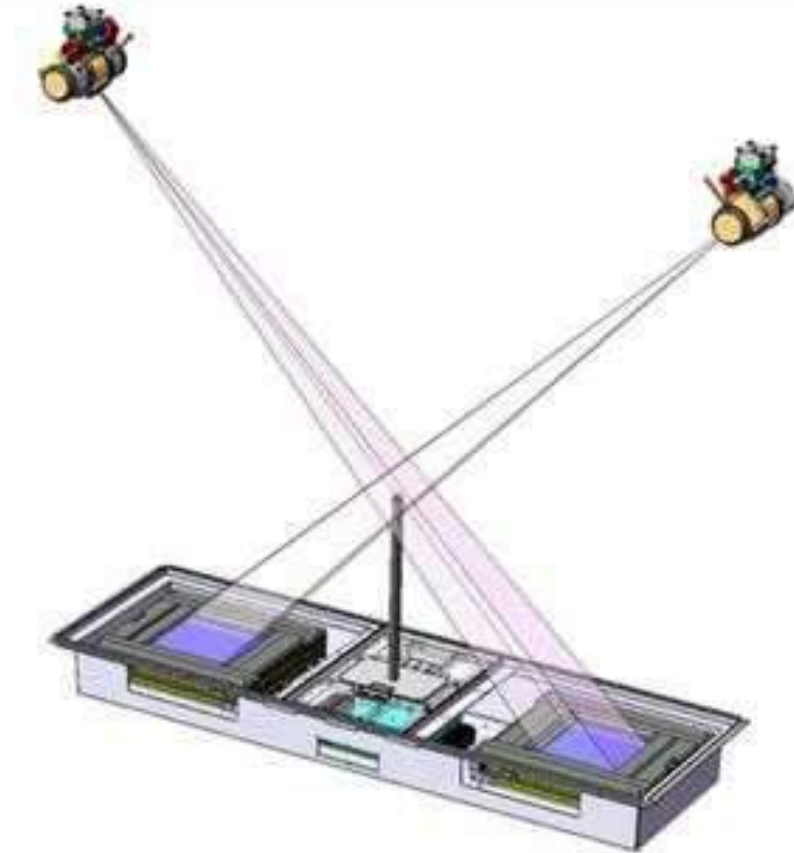


# Cyberknife Components





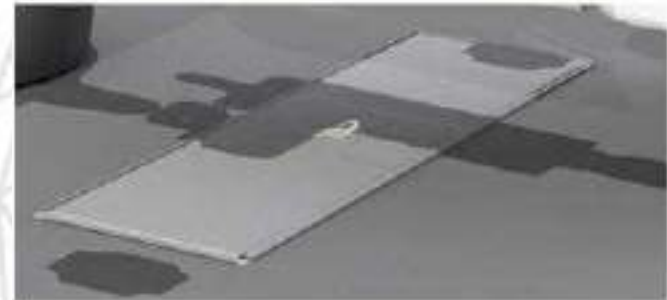
## Target Locating System (TLS)



## X-ray Sources



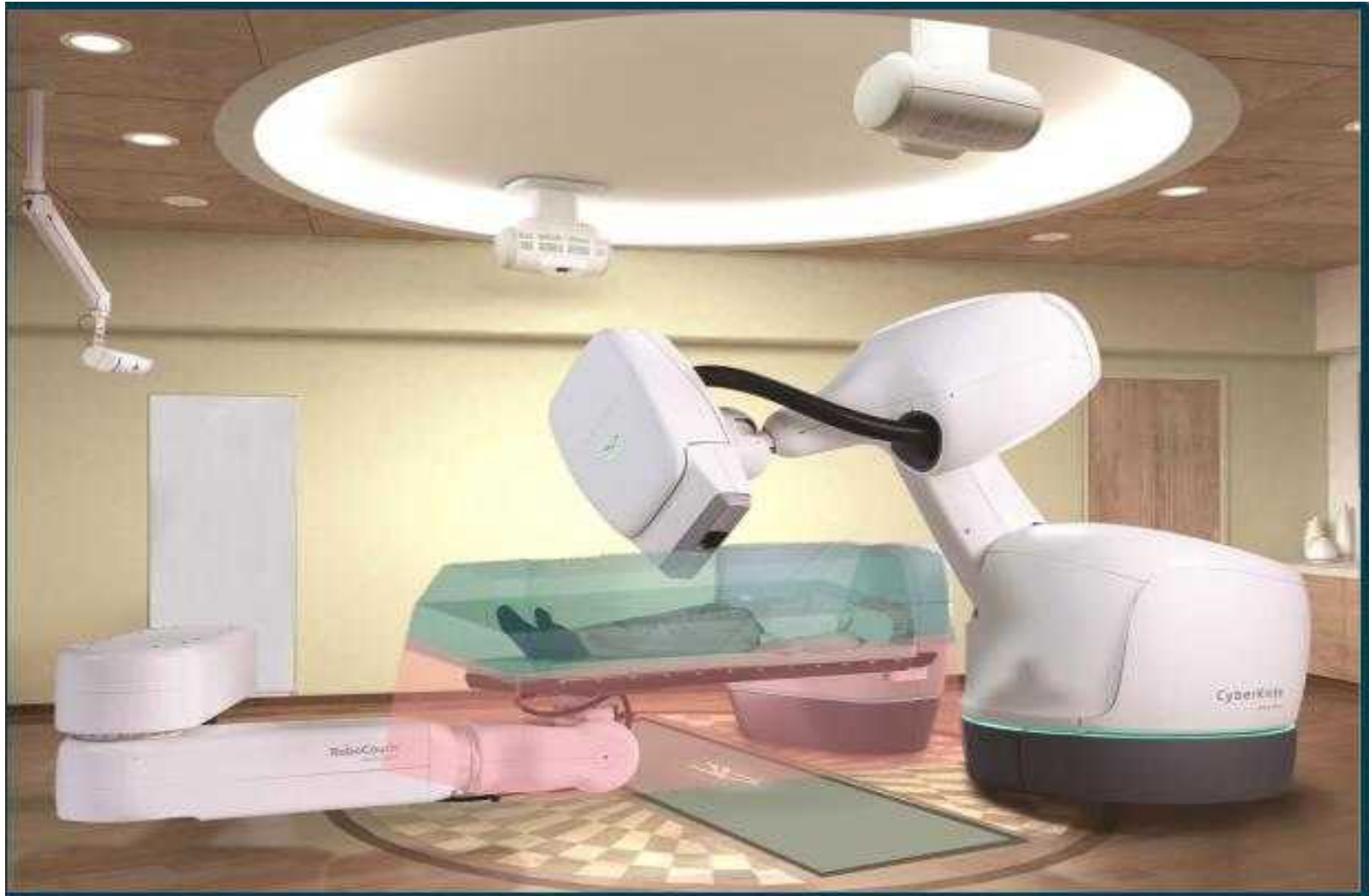
## X-ray Detectors



Real-time images every 5 -150 sec



# Safety Zones





# 3 Couches

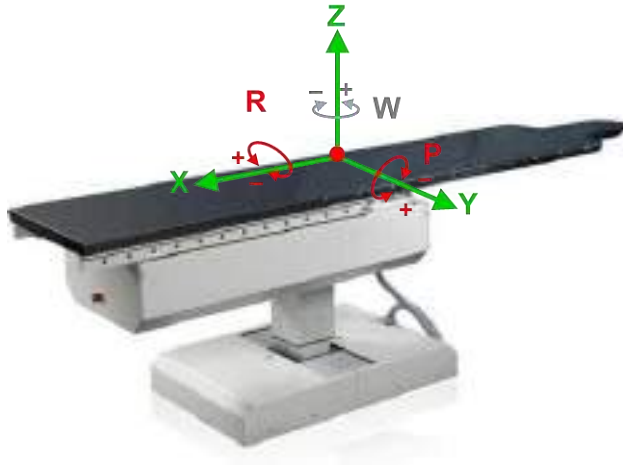
- Standard
- RoboCouch
- Seated Load



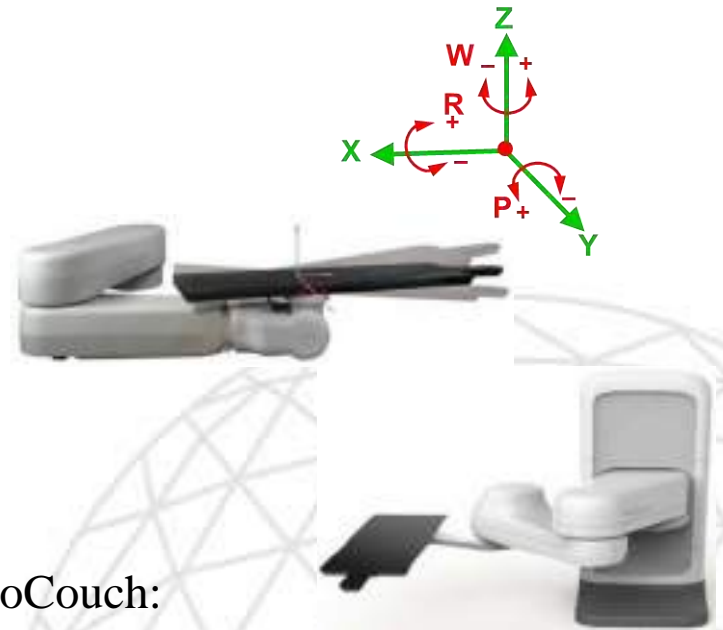


# Treatment Couch

®



- Standard Treatment Couch:  
Maximum Patient Load = 159 Kg



- RoboCouch:  
Maximum Patient Load = 227 Kg

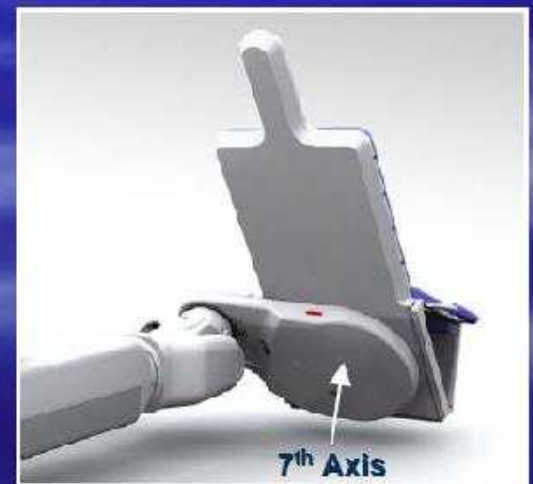
X: + = Superior, - = Inferior  
Y: + = Right, - = Left  
Z: + = Anterior, - = Posterior

R (roll): + = Roll Right, - = Roll Left  
P (pitch): + = Head Up, - = Head Down  
W (yaw): + = Clockwise, - = Counterclockwise (manual)



# Seated Load

- Adds 7<sup>th</sup> 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.



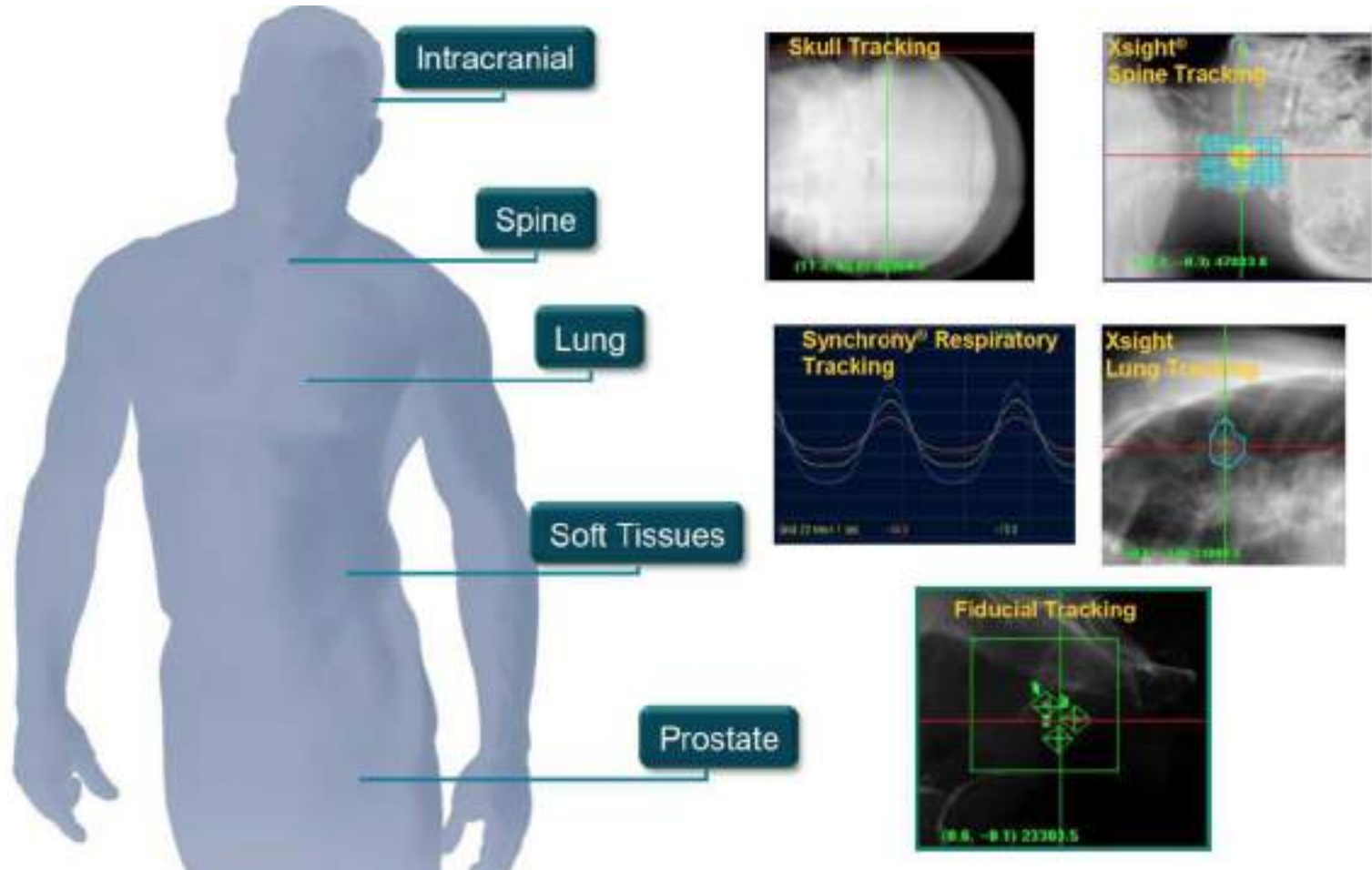
# Tracking Types

- 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

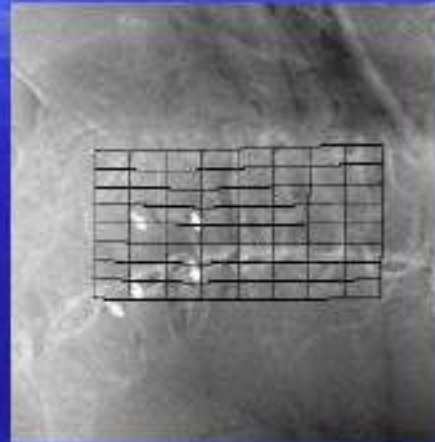
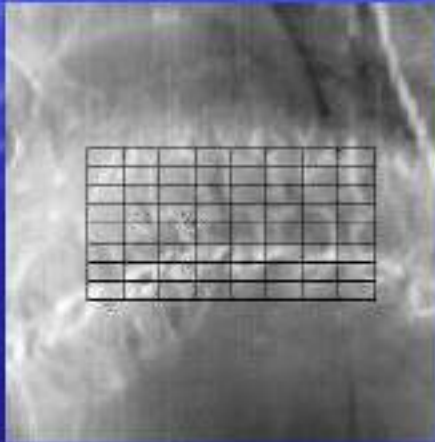
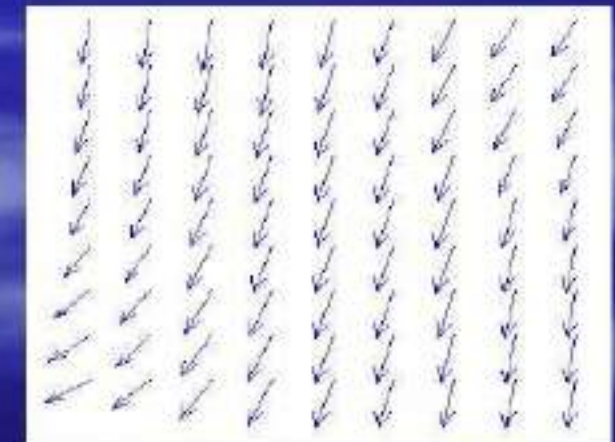
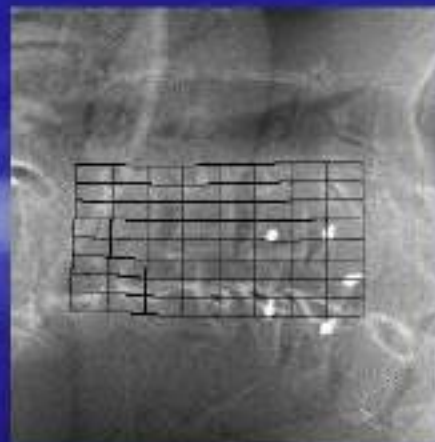
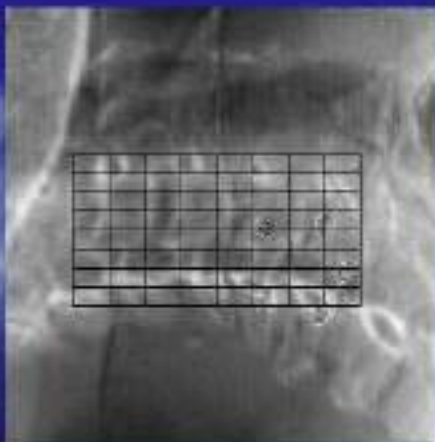


Image B





# 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 delivery 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





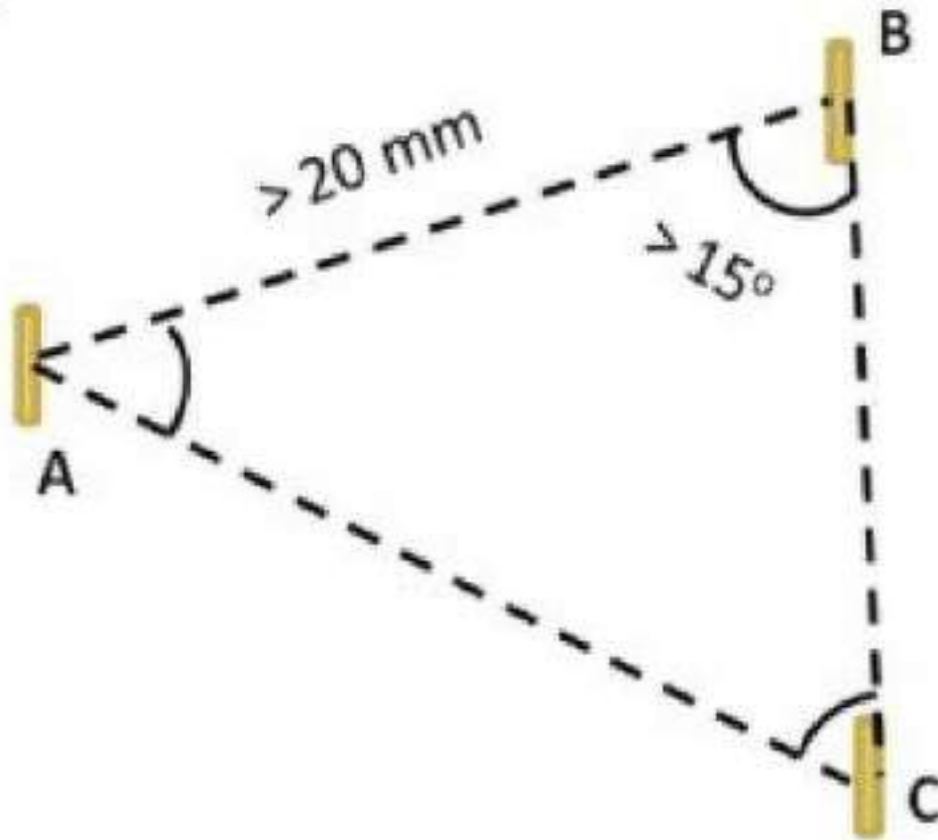
# FIDUCIAL TRACKING

- The fiducial tracking system enables tracking extracranial tumors by tracking implanted fiducial markers. Fiducial tracking 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.

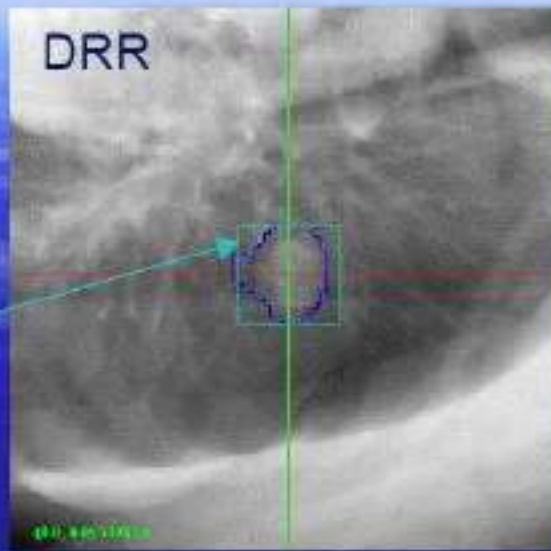
The parameter rigid body distance threshold in this system will give the maximum deviation of the fiducial between DRR and the x ray image



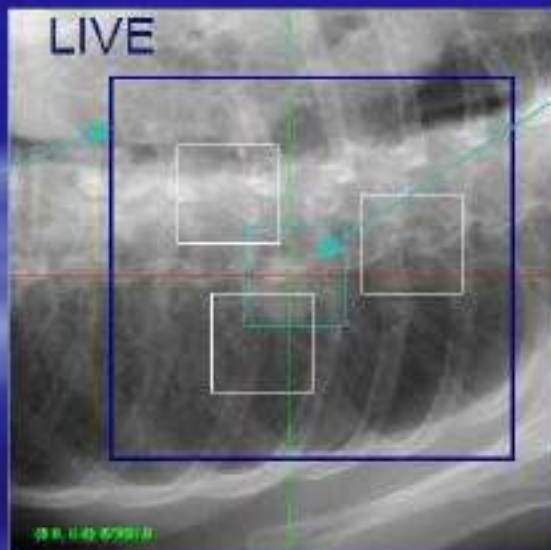
**B**



# XSight Lung



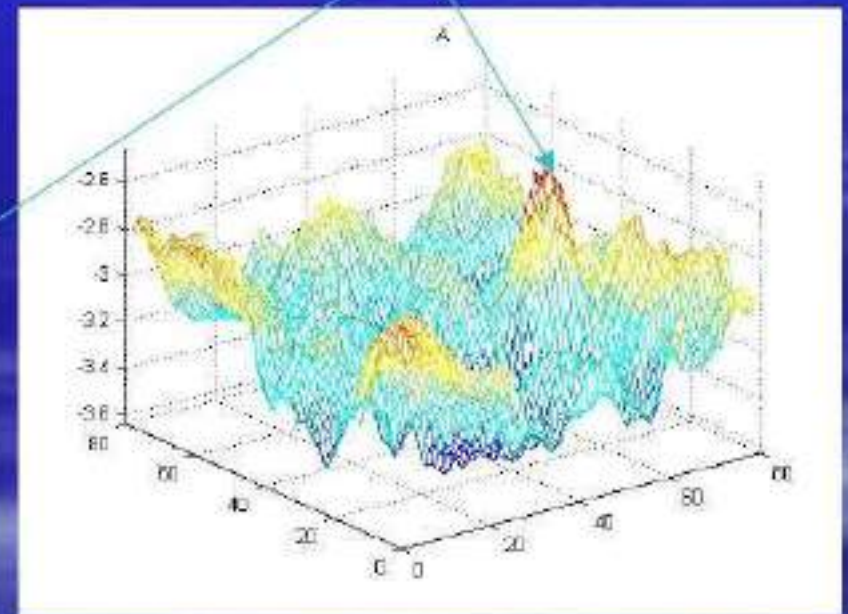
Matching window



Search window

Similarity Measure

Maximum similarity



# 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 the patient's breathing pattern, monitored in real-time, and the location of the target 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.

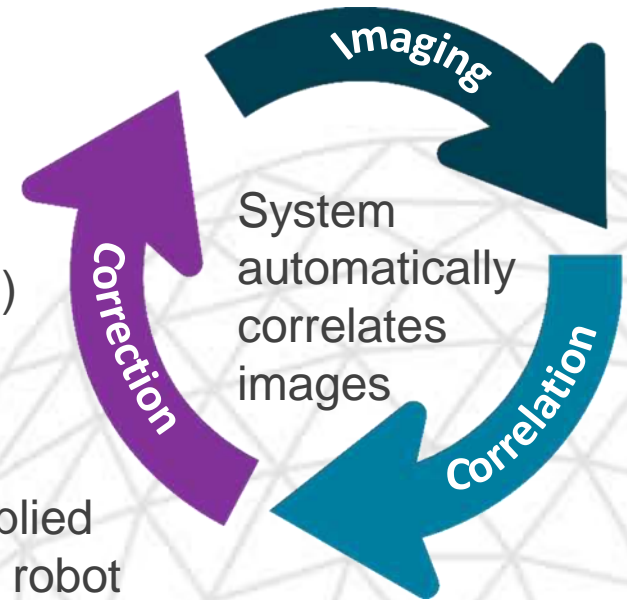




# CyberKnife System Treatment Automation



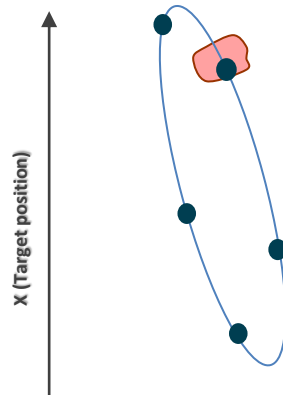
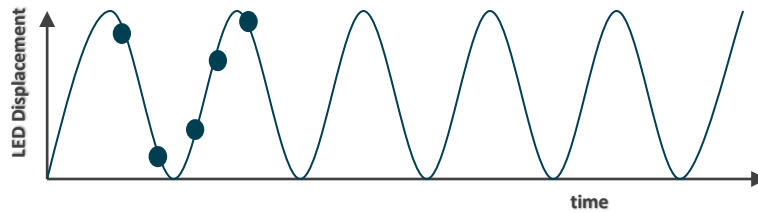
Images taken at user-set interval (5-150 seconds)



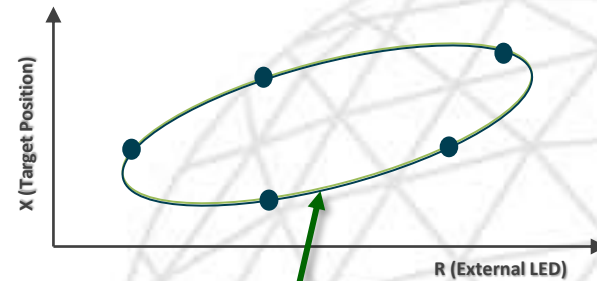
- Values applied directly by robot
- System always corrects for residual offsets



# How it works: model generation



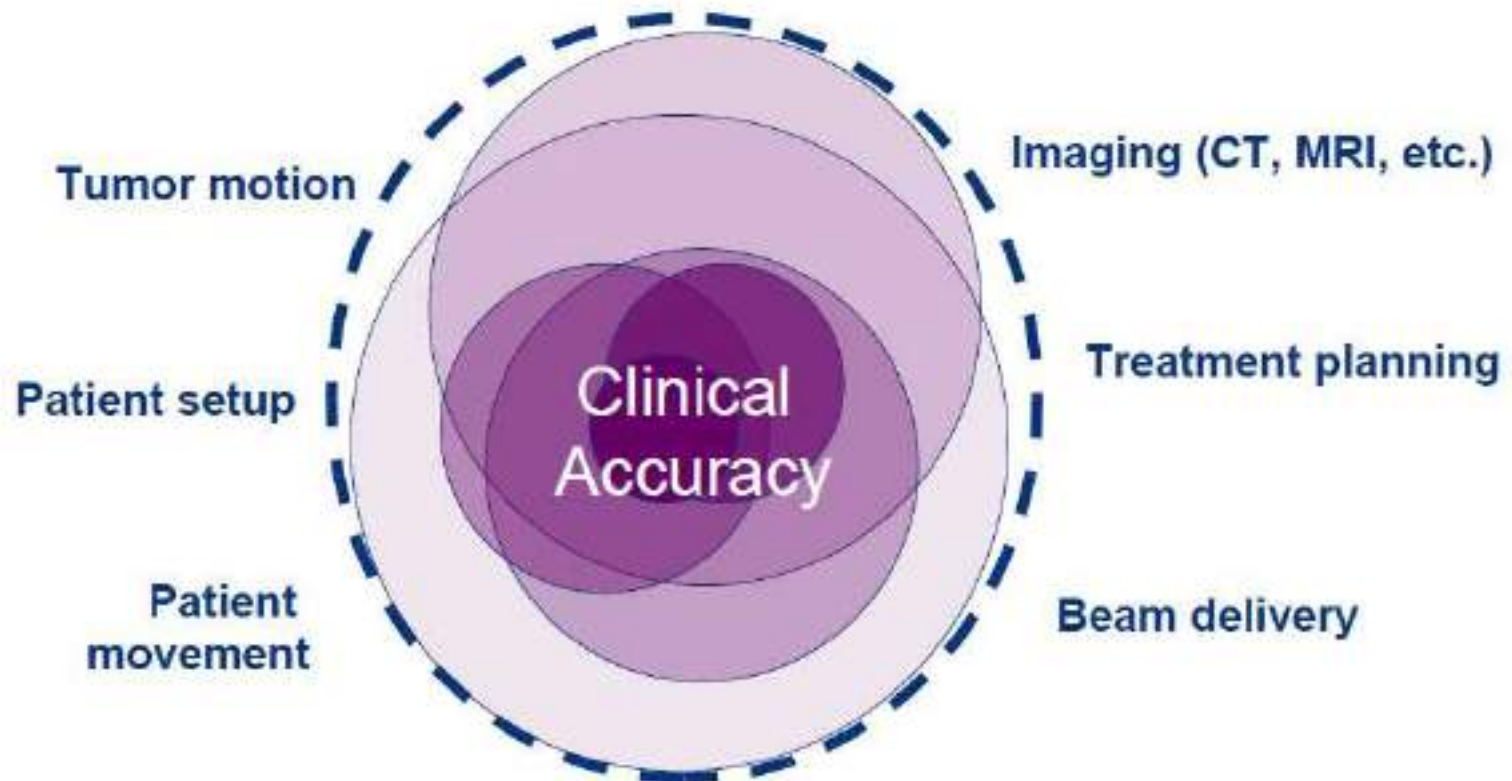
## Model creation





# 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

	<i>Site 1</i>	<i>Site 2</i>	<i>Site 3</i>	<i>Mean</i>	<i>SD</i>
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  $0.70 \pm 0.33$  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
<b>Immobilization device</b>	Rigid frame	Orfit	CK has favorable orfit
<b>RT source</b>	Co60	6MV LA	GK need to replace sources every 5/6 yrs
<b>Planning</b>	No complex planning	Inverse planning	Favorable dosimetry in CK
<b>Planning method</b>	Simple	Complex	Even neurosurgeons can plan in GK
<b>Isodose pres</b>	Usually 50%	Usually 80-95%	GK: more dose heterogeneity
<b>Fractions</b>	Single	May treat multiple fraction	Radiobiology favorable in CK
<b>Tumour size</b>	Only smaller lesions can be treated	Larger lesions also can be treated in fractionated schedule	Increased indications with CK
<b>Energy source</b>	Radiation	Electricity	GK can work with less electricity
<b>Verification</b>	Not possible	Possible	Even Intra-fraction movement can be corrected
<b>Indications</b>	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