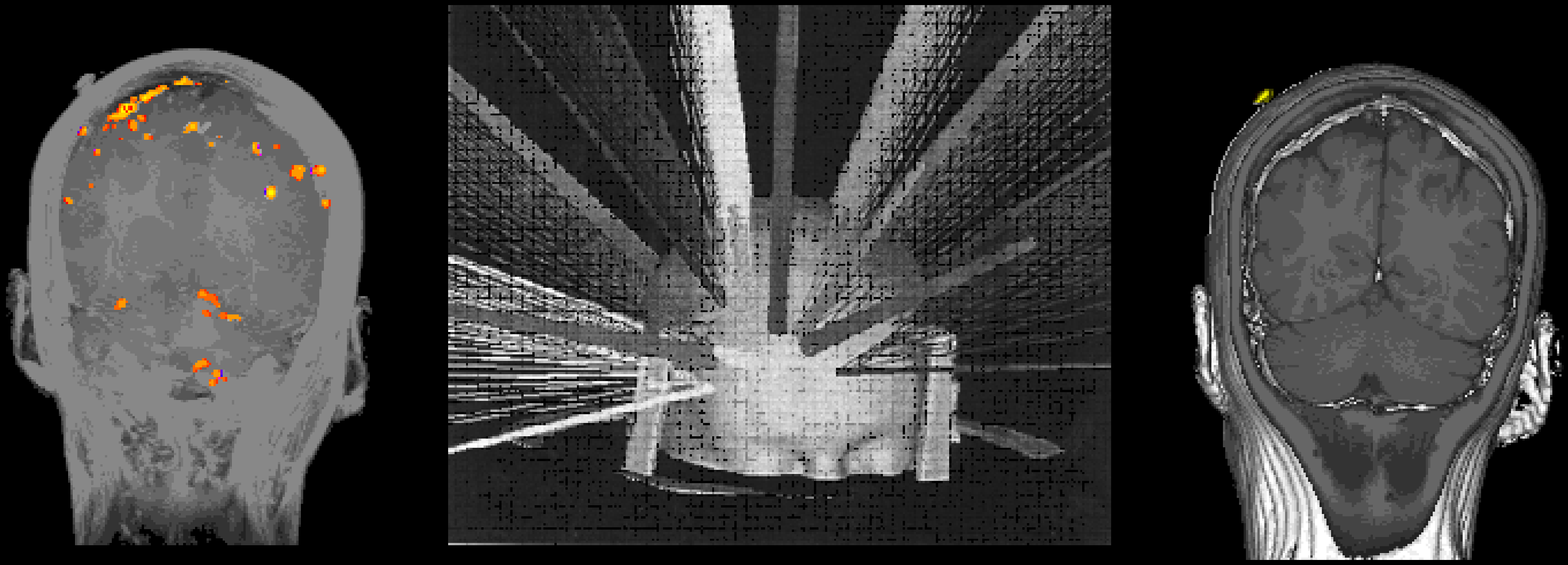
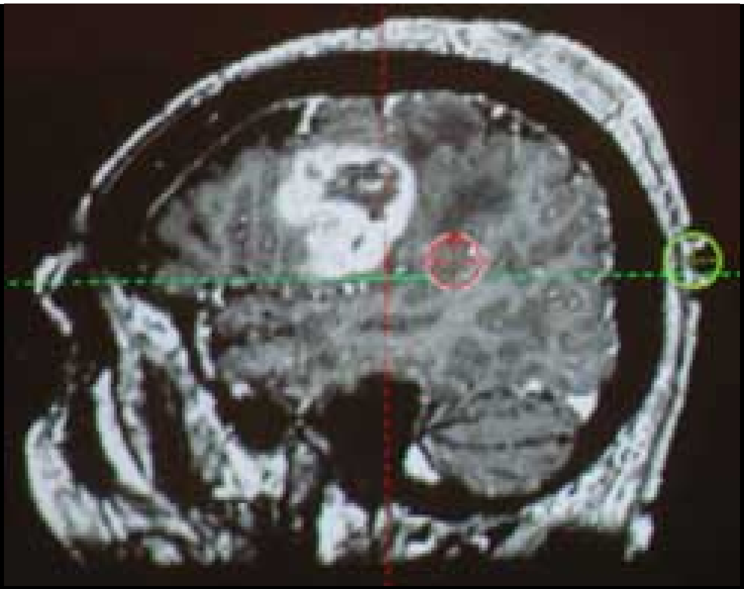
STEREOTACTIC RADIOSURGERY

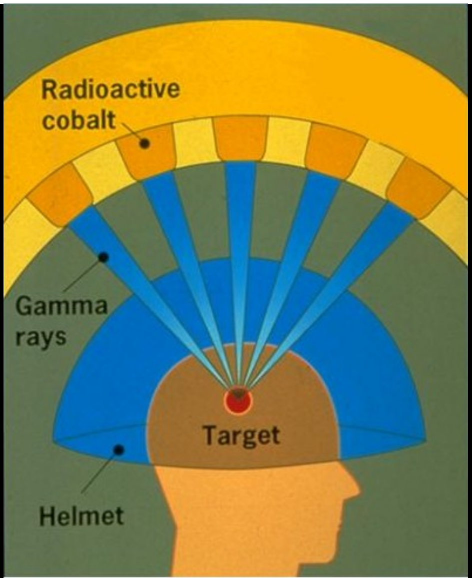


Stereotactic radiosurgery (SRS) is a way of treating brain disorders with a precise delivery of a single high dose of radiation in a one-day session. Treatment involves the use of focused radiation beams delivered to a specific area of the brain to treat abnormalities,(tumors or other functional disorders hearing, etc.) and the brain stem.

Professor Leksell & First Gamma Knife

The concept of the Radiosurgery began in 1949 with Professor Lars Leksell's center of arc principle, whereby any intracranial target could be reached from any point around the convexity of the skull. Dr. Leksell recognized the need for a tool to allow for the treatment of deep-seated lesions in the brain without entering the skull and the hazards of open surgery.



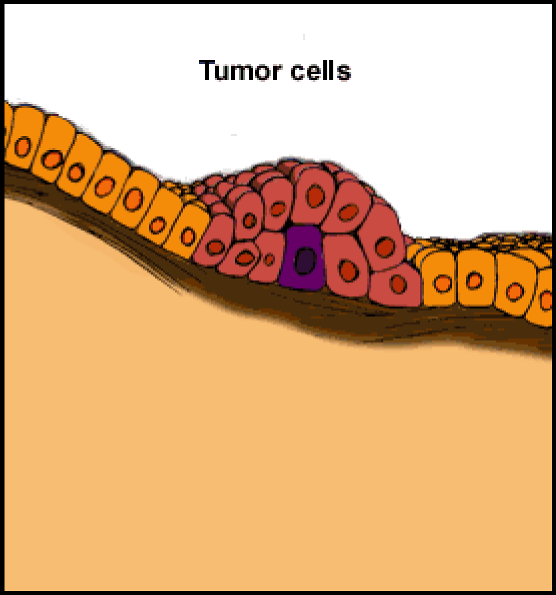


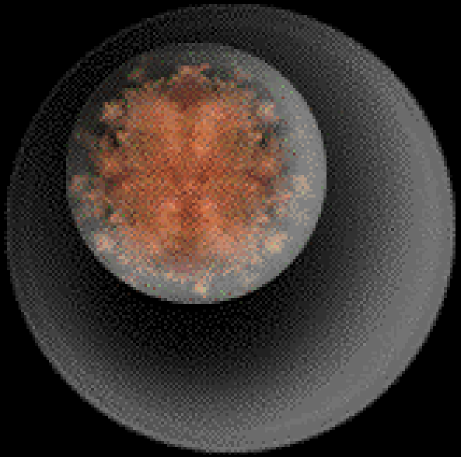
He envisioned a deep-seated intracranial target being irradiated by multiple beams of externally applied ionizing irradiation without opening the skull, hence without the risks of open surgery such as hemorrhage, infection, and cerebral spinal fluid leakage.

Dr. Leksell's gamma knife works by a process called stereotactic radiosurgery, which uses multiple beams of radiation converging in three dimensions to focus precisely on a small volume, such as a tumor, permitting intense doses of radiation to be delivered to that volume safely at one session.

Treatment that is fractionated over several days may be referred to as stereotactic radiotherapy as opposed to stereotactic radiosurgery.

Following extensive experimental and clinical research, Dr. Leksell developed the first Gamma Knife in 1967 at the Karolinska Institute in Sweden. This unit used 179 cobalt sources.



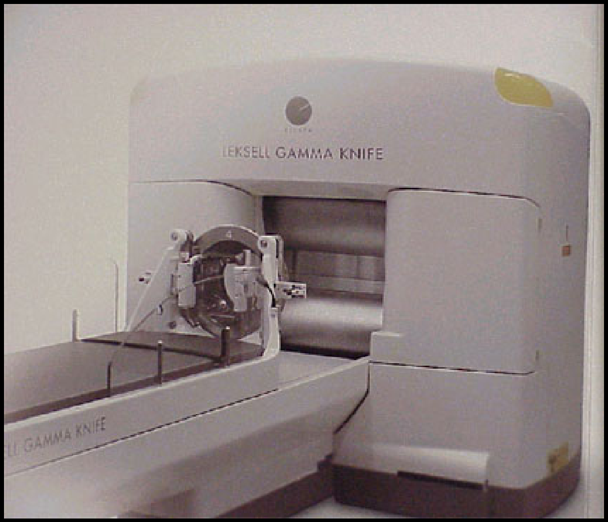


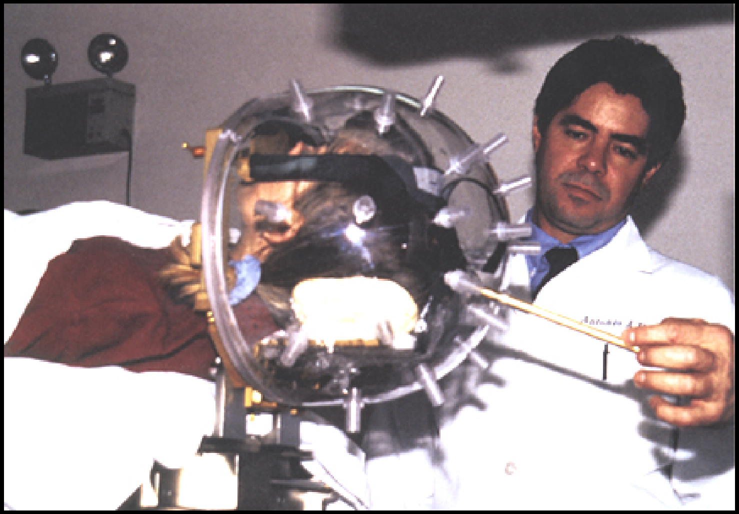
Stereotactic radiosurgery works the same as all other forms of radiation treatment. It does not remove the tumor or lesion, but it distorts the DNA of the tumor cells. The cells then lose their ability to reproduce and retain fluids. The tumor reduction occurs at the rate of the normal growth rate of the specific tumor cell. In lesions such as AVMs (a tangle of blood vessels in the brain), radiosurgery causes the blood vessels to thicken and close off.

There are three basic forms of stereotactic radiosurgery represented by three different technological instruments. Each instrument operates differently, has a different source of radiation and may be more effective under different circumstances. The three are:

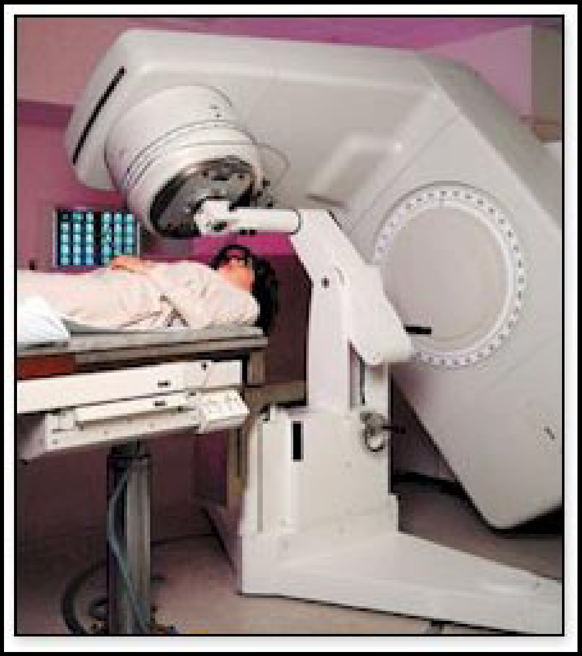
- Particle beam (proton)
- Cobalt60 based (photon)
- Linear accelerator based

The particle beam or cyclotron is in limited use in the United States. In addition to brain tumors, it also treats body cancers in a fractionated manner. The particle beam facility is extremely large, but because of the fundamental characteristics of protons, the treatment is quite effective.





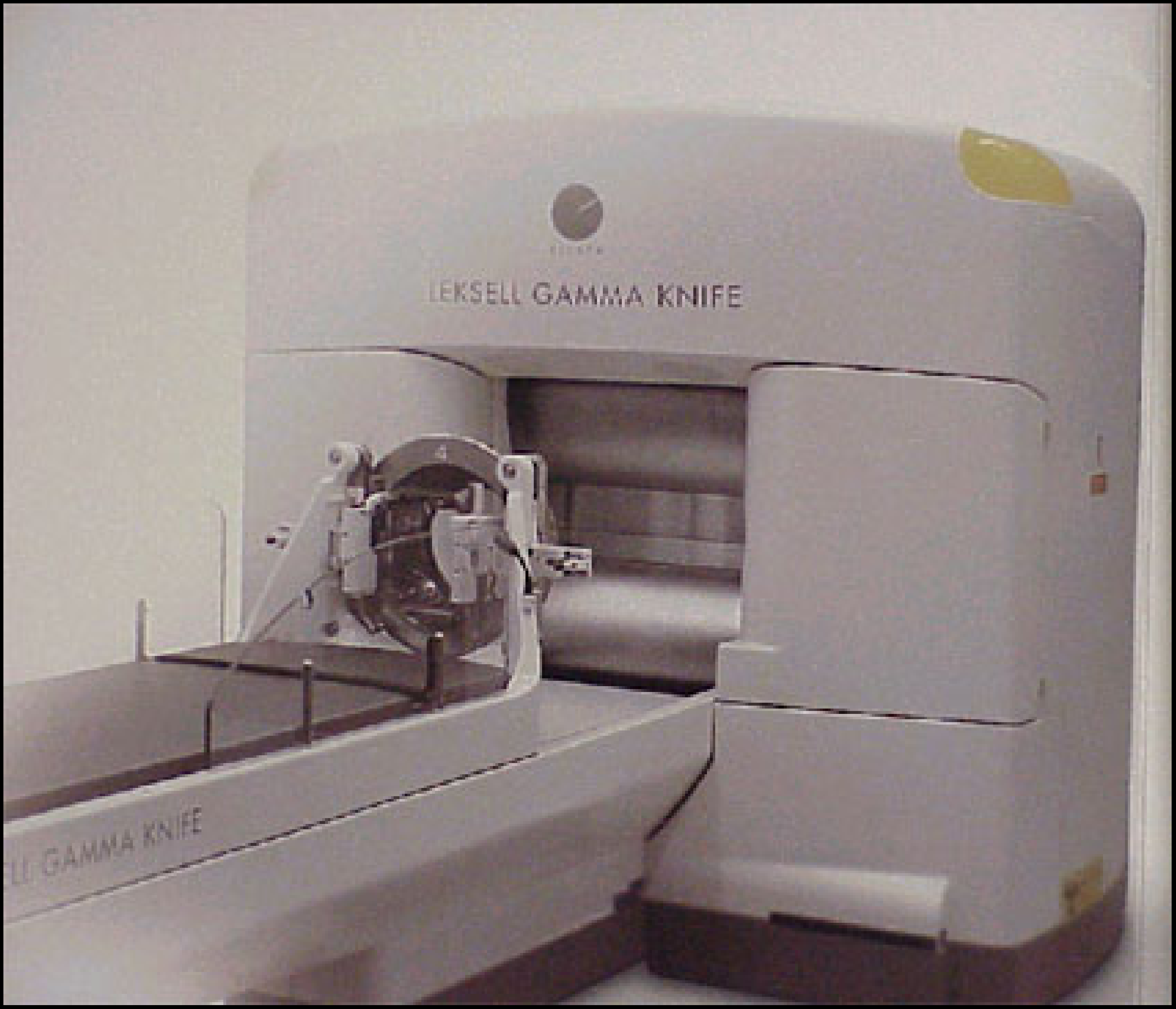
The Gamma Knife® does not move during treatment, thus providing a high degree of precision within the brain. The unit today is much the same as when it was developed. The machines utilize multiple sources of radiation, which allows for less damage to healthy tissue and better targeting. These machines are ideal for smaller tumors (less than 3.5 cm) and for functional disorders of the brain.

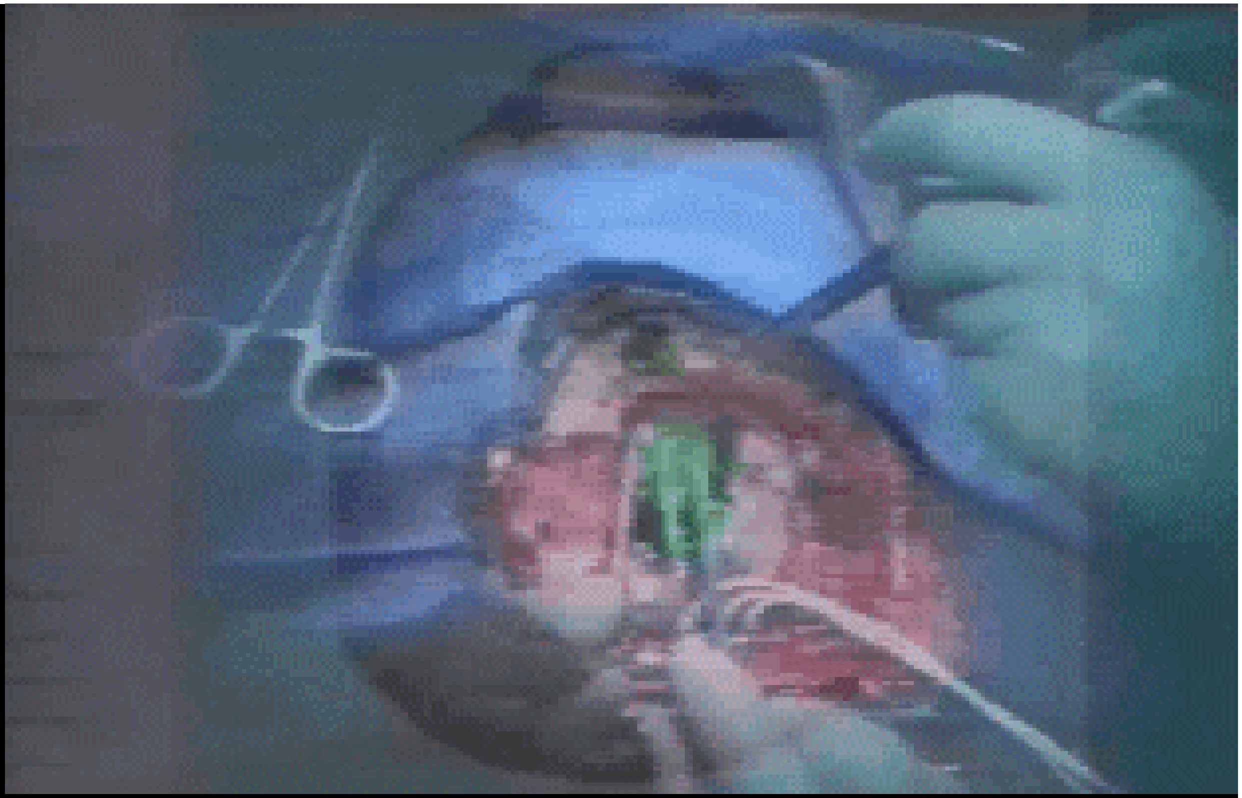


The linear accelerator based radiosurgery machines are also prevalent throughout the world. One benefit of this technology is its ability to easily treat large tumor volumes (over 3.5 cm) by treating over several sessions. When treating over time, it is called fractionated stereotactic radiotherapy and not stereotactic radiosurgery (which is a one-session treatment). Linear accelerator based machines are not dedicated to just treatments within the brain.

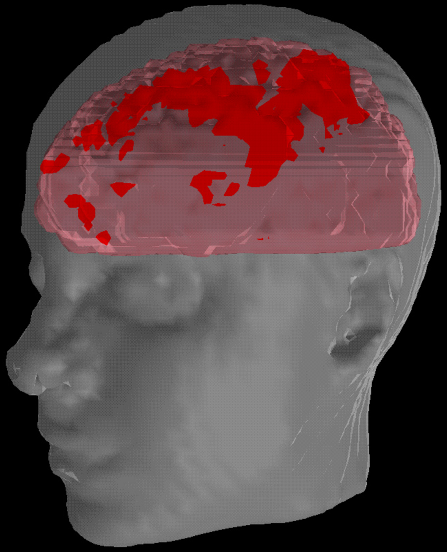
The linear accelerator based machines utilize one large intense radiation beam that is redirected in many "arcs" to lessen the effect on healthy tissue. The linear accelerator based machines can perform radiosurgery on larger tumors and can fractionate these treatments over several days, having a flexibility that is not available with other machines. These treatments that are given over time are referred to as fractionated stereotactic radiotherapy or FSR or SRT (stereotactic radiotherapy). Since the linear accelerator moves during treatment, the degree of precision is somewhat less than with cobalt 60 machines.

GAMMA KNIFE



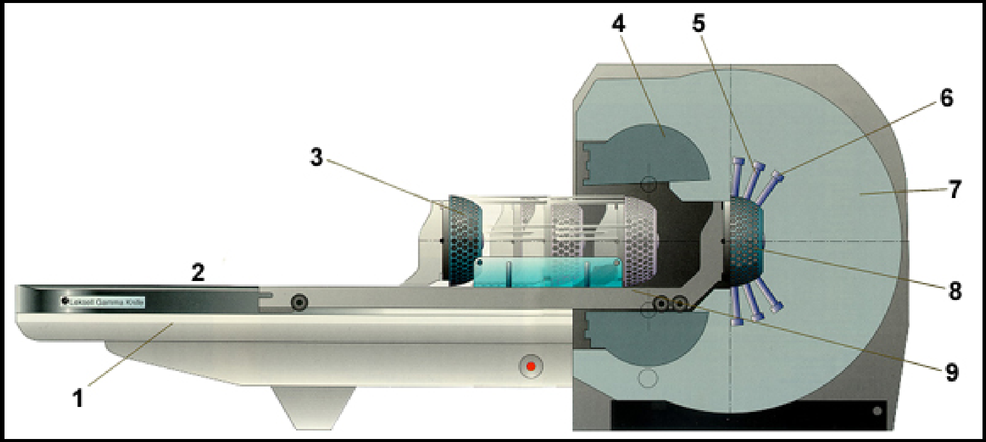


What is the Gamma Knife?
The Gamma Knife is a neurosurgical instrument that allows a surgeon to perform brain surgery without a scalpel or actually entering the skull. This way there is little damage to the brain and as much function as possible can be preserved.

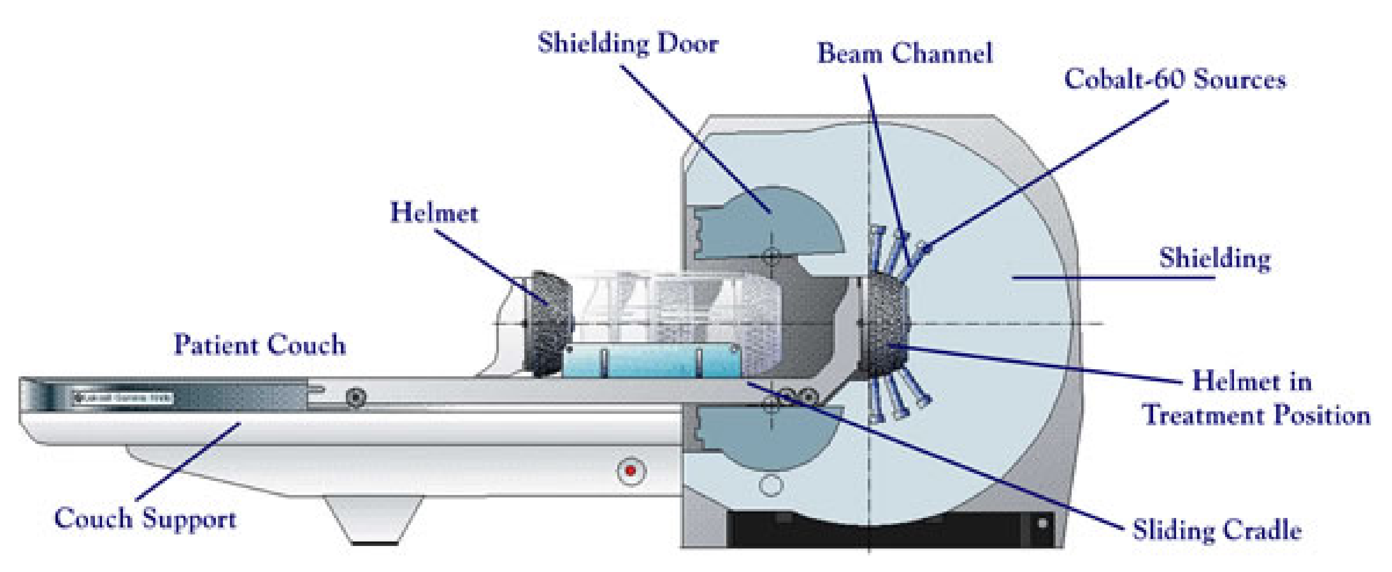


This form of non-invasive surgery -- also known as radiosurgery -- uses 201 highly focused beams of Cobalt 60 Radiation to produce biological effects on tissues inside the intact skull. The treatment is done in a single sitting and therefore also has the benefit of shorter hospital stays for most patients and fewer side effects. The beams are focused through a helmet attached to the patient. The cells in the target area are killed at the time of operation, and are subsequently cleared by the immune system.

There are three current versions of the Leksell Gamma Knife

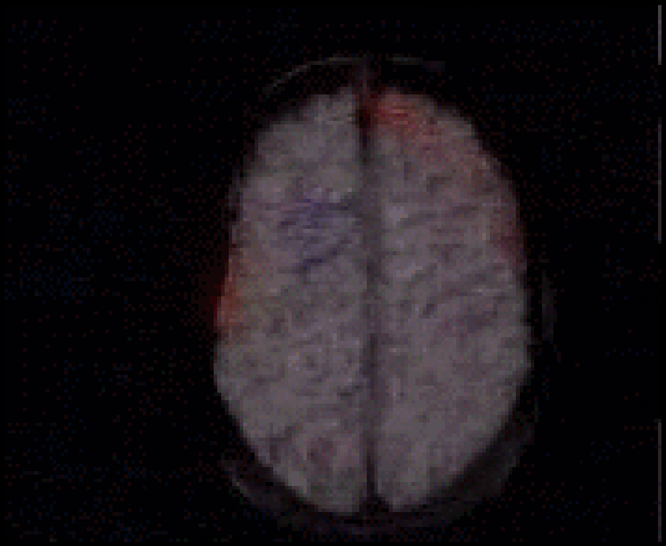


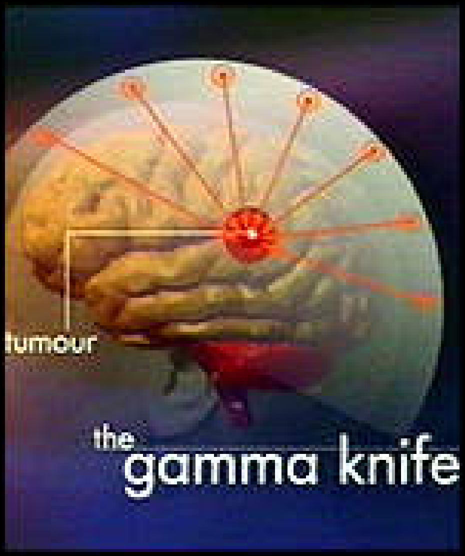
Although the physical appearance of each model differs, the internal design leads to dose profiles that differ only slightly.



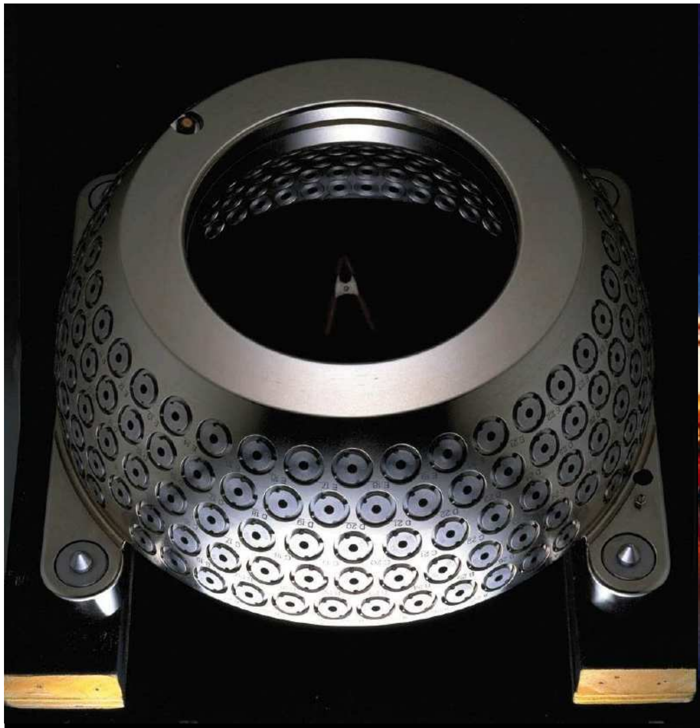
Each system consists of six components: the radiation unit, individual collimator helmets of four different beam diameters, the patient couch, hydraulic bed system in the U unit, the control console, and the treatment planning computer system.

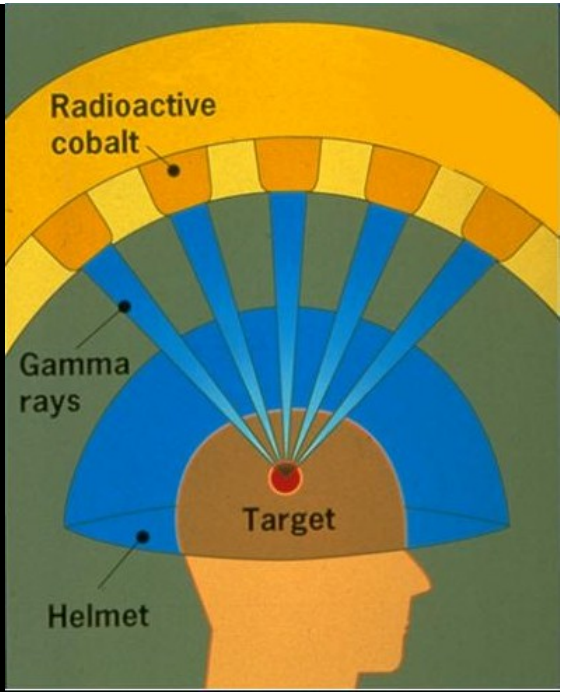
How does it work?



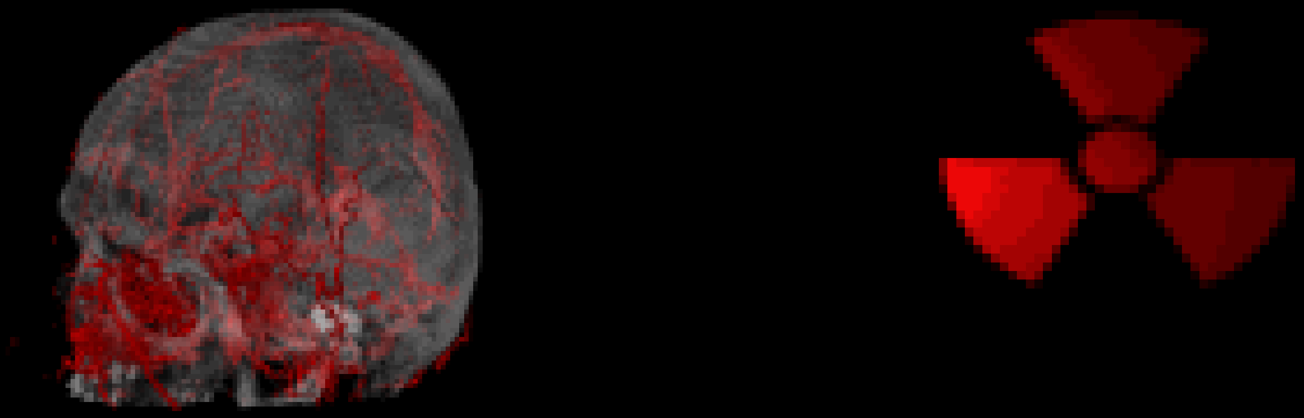


The Gamma Knife uses many intersecting beams of gamma radiation to destroy a tumor or vascular malformation in the head.

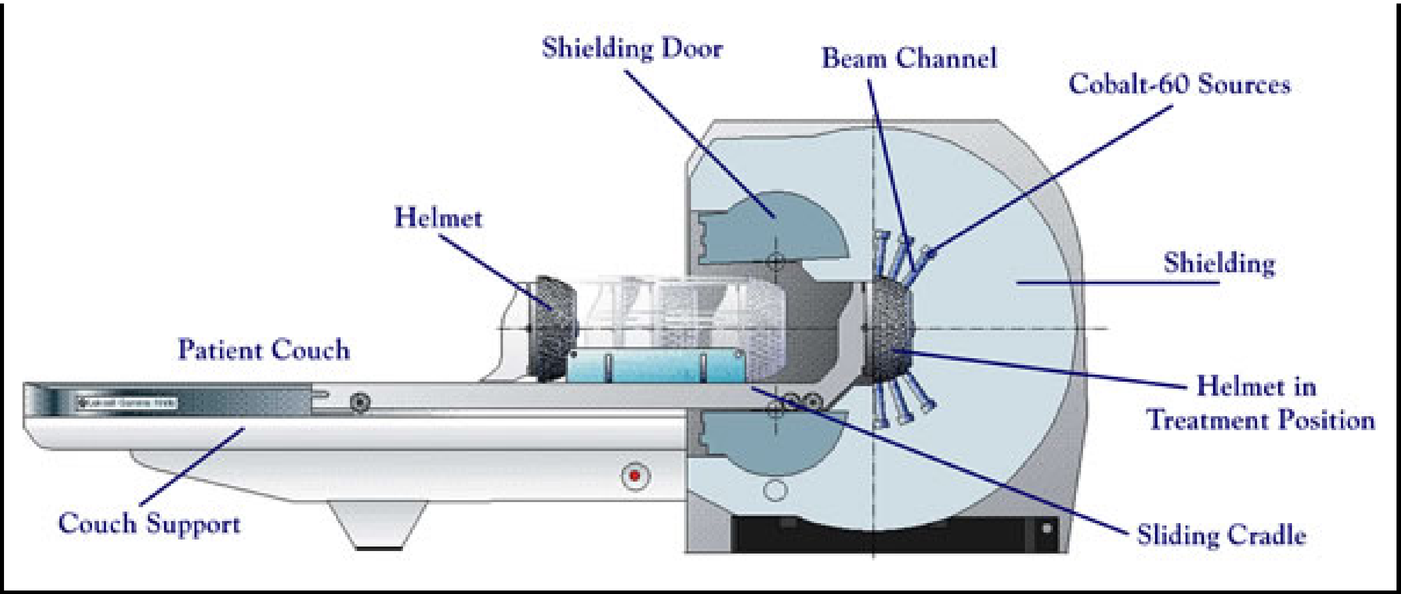


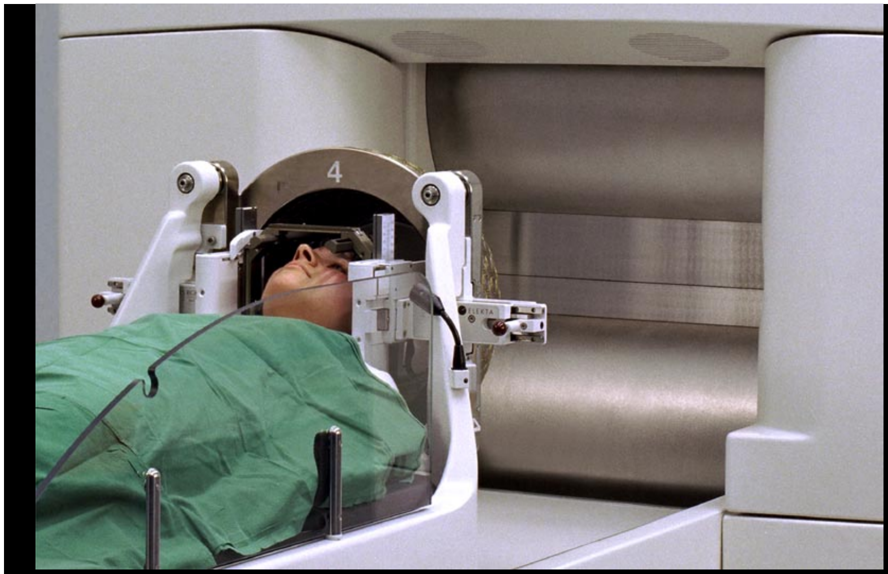


Cobalt gamma ray beam sources are arrayed in a hemispherical or annular array and aimed through a collimator to a common focal point.

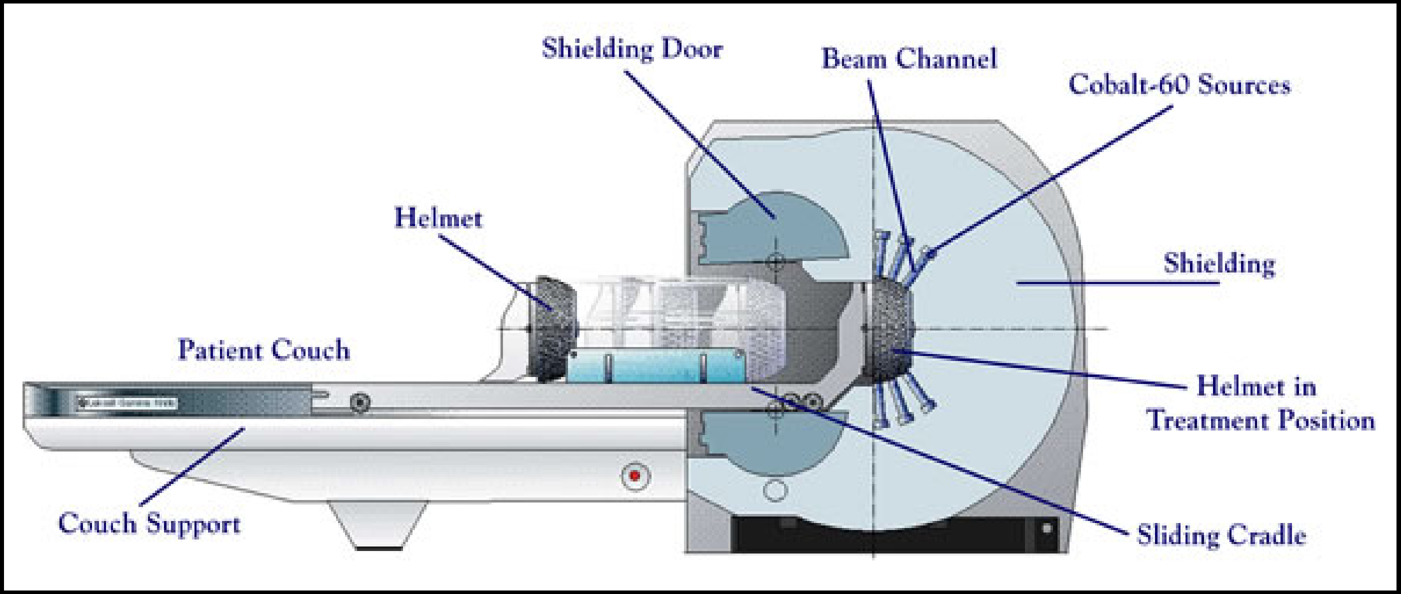


The tumor receives a destructive dose of radiation, while little radiation is absorbed by adjacent, normal brain.

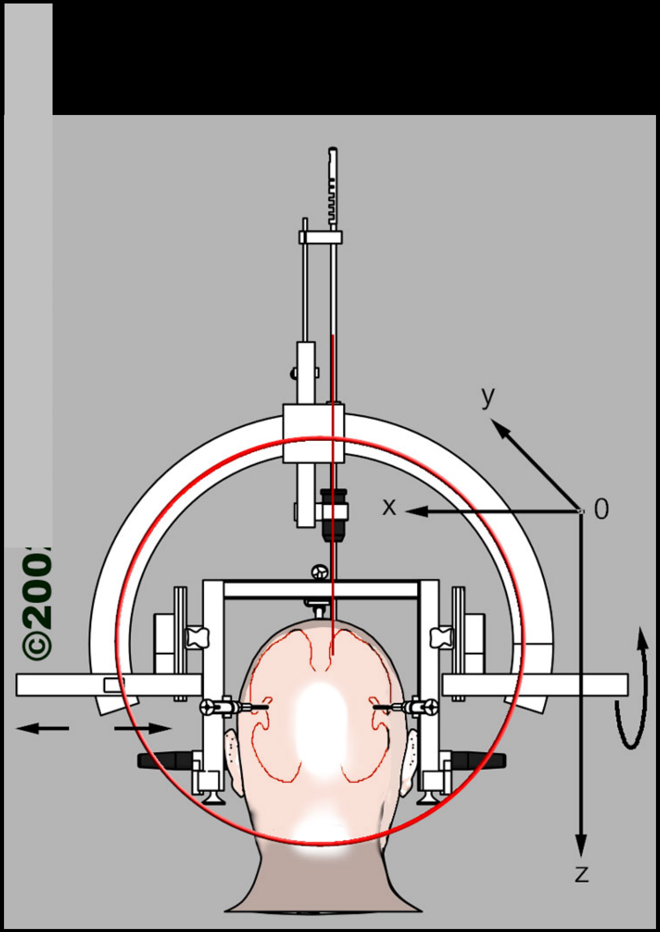

Shielding Door
Beam Channel
Cobalt-60 Sources
Helmet
Shielding
Patient Couch
Helmet in Treatment Position
Couch Support
Sliding Cradle



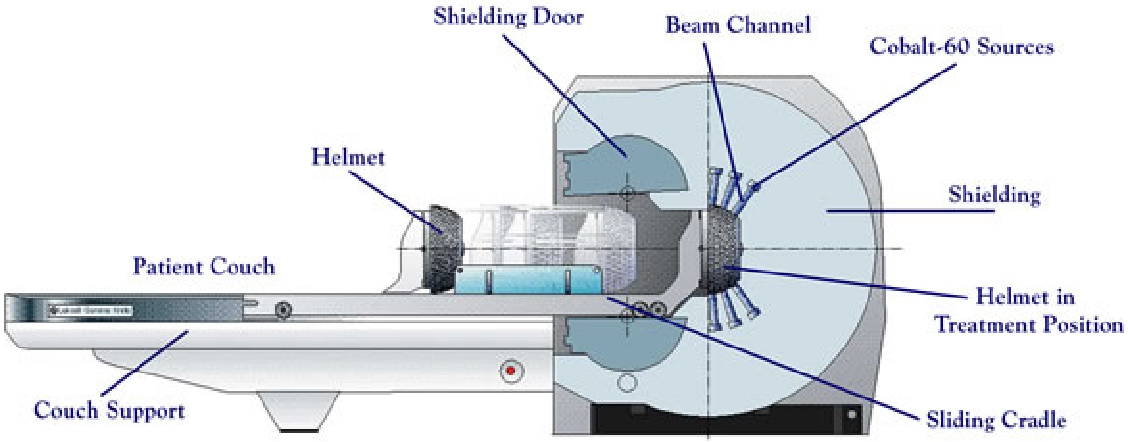
In each helmet, removable 4, 8, 14, or 18 mm tungsten collimators with circular apertures are used to create different diameter fields at the focus point. Modification of the isodose distribution can be achieved using multiple isocenters with different collimators, or use of beam plugging



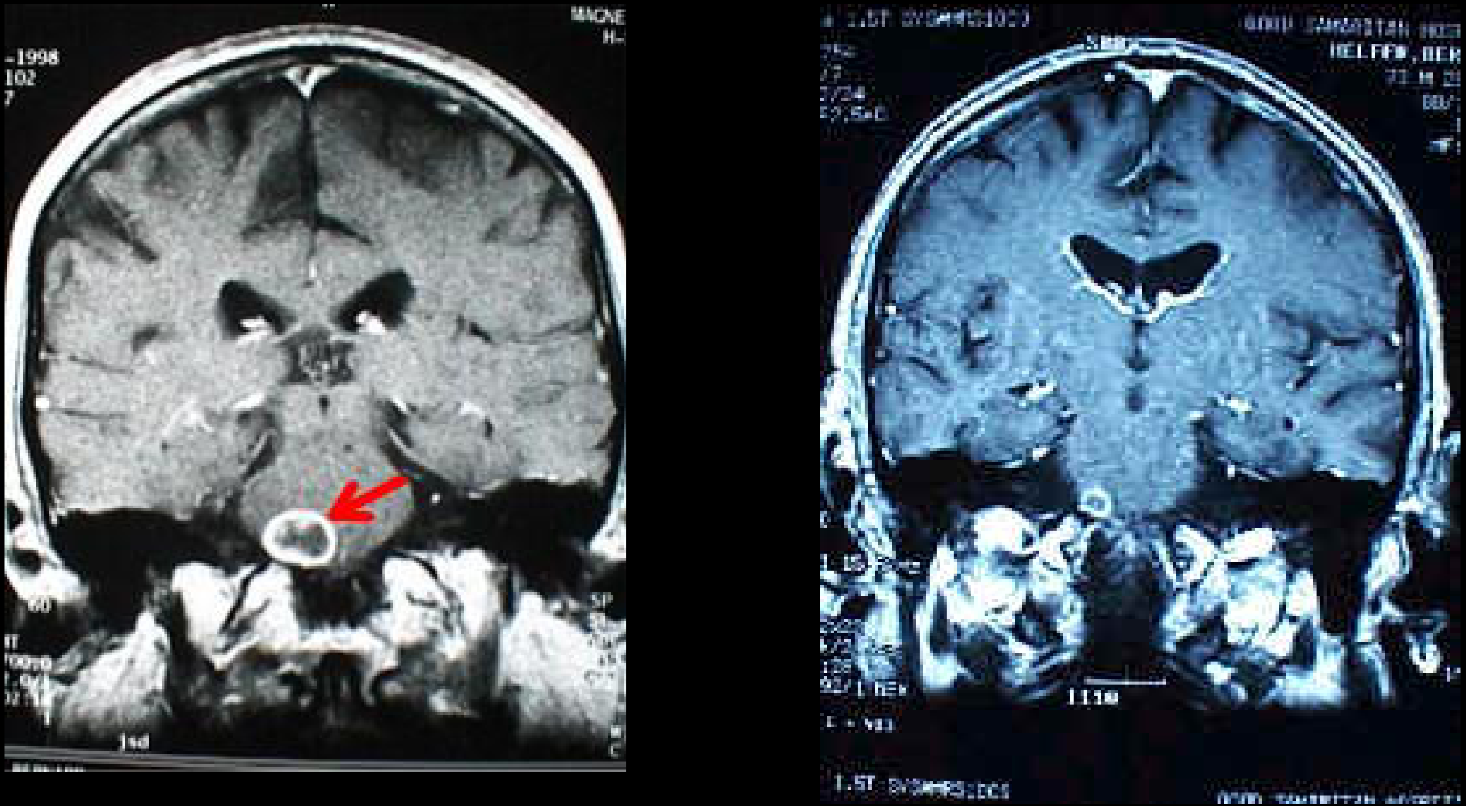
Movement of the treatment table in and out of the radiation unit, and opening of the shielding door as performed by the hydraulic or electrical power system, are the only sources of movement during the procedure.



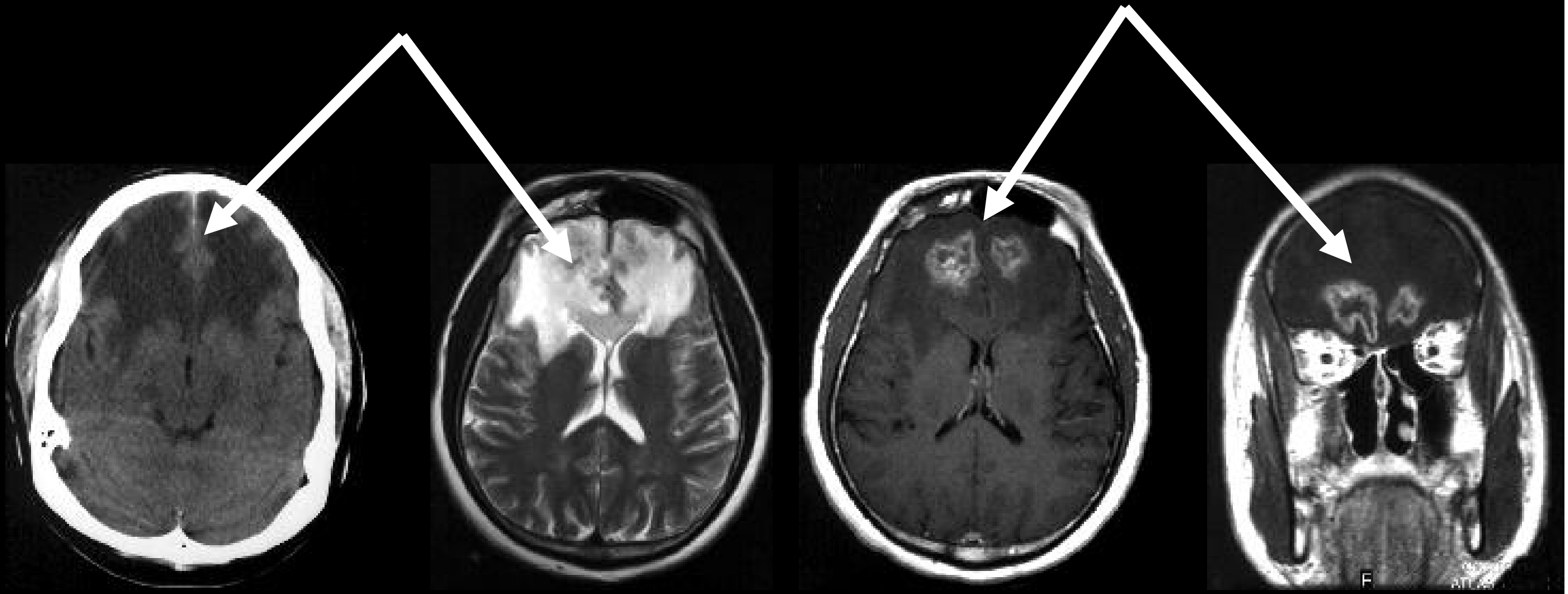
Stereotactic radiosurgery is limited to the head as this area can be immobilized with skeletal fixation devices that completely restrict the head's movement , permitting the most precise and accurate treatment. Treatment without a skeletal fixation device for a one-session treatment is not recommended because of the high potential for damage to healthy brain tissue, cranial nerves, optic nerves.



It is precise and accurate: The dose each patient receives is "custom-designed" using a computer and in consultation with a radiation physicist and a radiation oncologist. Mechanical accuracy as dictated by the manufacturer should be within 0.5 mm.



What are the Gamma Knife's primary uses?
Currently, the Gamma Knife is used primarily to treat benign brain tumors, AVMs, acoustic neuromas, pituitary adenomas, craniopharyngiomas, brain metastases, other tumors of the skull base, pineal region tumors, and trigeminal neuralgia.



The primary determining factor in choosing Gamma Knife therapy is the size of the desired target. Lesions larger than 3.5 centimeters in diameter are difficult to treat with the Gamma Knife alone, and may result in serious radiation necrosis complications approximately six to 18 months post treatment.

Most often larger lesions can be treated by a combination of Gamma Knife plus open surgery, embolization, or other therapies. Occasionally exceptions are made to treat larger lesions with the Gamma Knife after consideration of the patient's overall condition, review of alternative options and the goal of therapy for the individual.

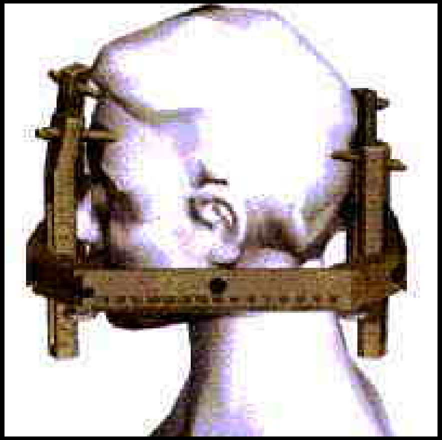
Treatment of arteriovenous malformations causes endothelial proliferation that results in obliteration over a period of one to two years. Multiple isocenters are used to conform the dose to the target, and minimize radiation exposure of brain tissue adjacent to the target.

How is Gamma Knife surgery performed?

First a stereotactic frame is attached to the head.


M.R.I.

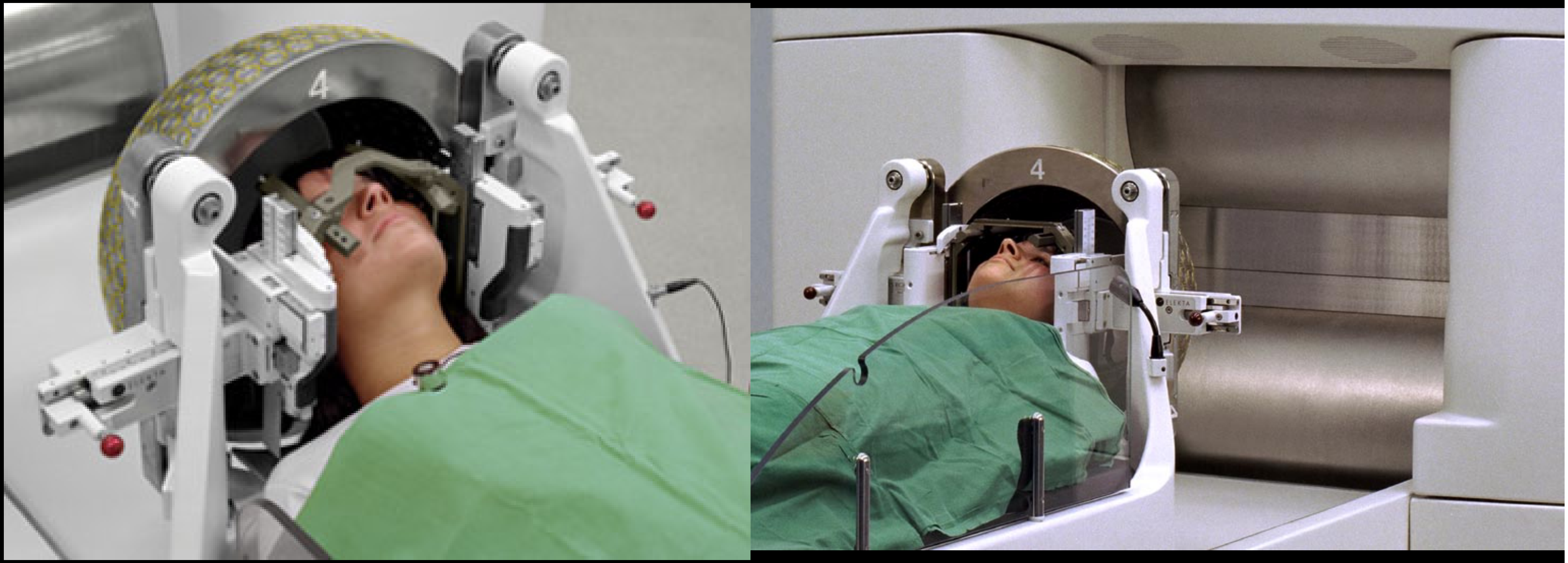

ELEKTA
LEKSELL GAMMA KNIFE
14
ELEKTA
APS LEFT



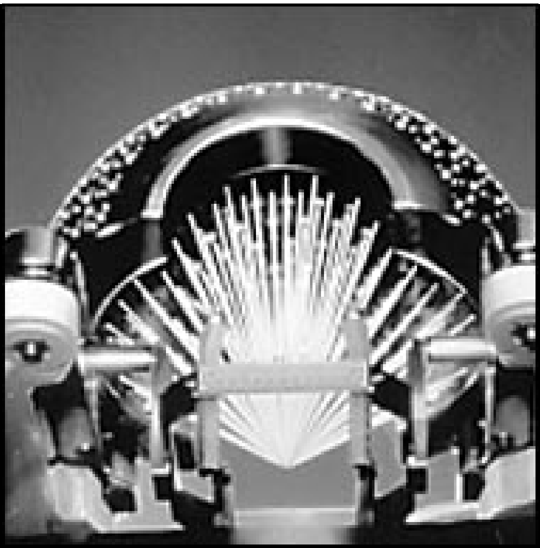
The stereotactic frame is a rectangular ring to which four metal posts are attached which fits over the head. Four pins are then attached to the skull after the skin has been cleansed with alcohol and local anesthesia infiltrated into the scalp. To keep the device steady while the stereotactic frame is being placed, temporary ear bars will rest in the ear canals, which are removed once the frame has been attached to the skull.

Next the head is imaged in a CT scanner or MRI scanner while the patient wears the stereotactic frame. For vascular malformations, an angiogram is obtained as well…

A series of images is taken and transferred to the computerized treatment planning system. The system localizes the target, determines its coordinates, and ensures that the radiation field conforms precisely to the target.



The head is positioned within the Gamma Knife so that the tumor is in the focal point of the gamma rays.

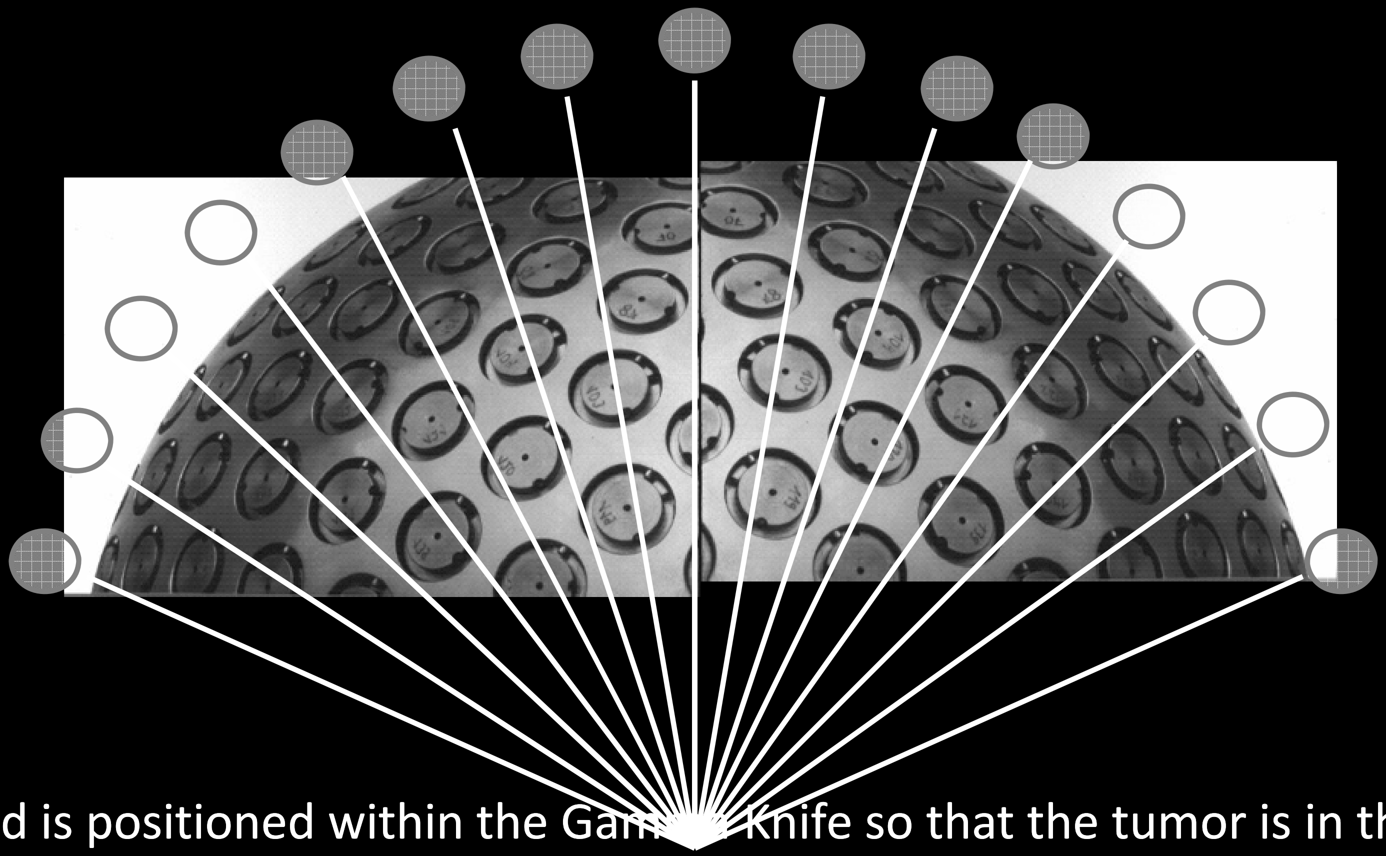


The treatment begins when the doors of the radiation unit open and the head of the couch moves into the treatment position. The number and length of treatments given may vary between 20 minutes to two hours, depending upon the size and number of areas to be targeted.

The unit consists of a permanent 18,000 kilogram shield surrounding the hemispheric or circular array of 201 cobalt-60 sources. Each beam channel has a source-bushing assembly, a tungsten alloy pre-collimator, and a primary collimator. Secondary collimation is achieved via one of the four helmets containing 201 channels of different sizes.

In each helmet, removable 4, 8, 14, or 18 mm tungsten collimators with circular apertures are used to create different diameter fields at the focus point. Modification of the isodose distribution can be achieved using multiple isocenters with different collimators, or use of beam plugging.

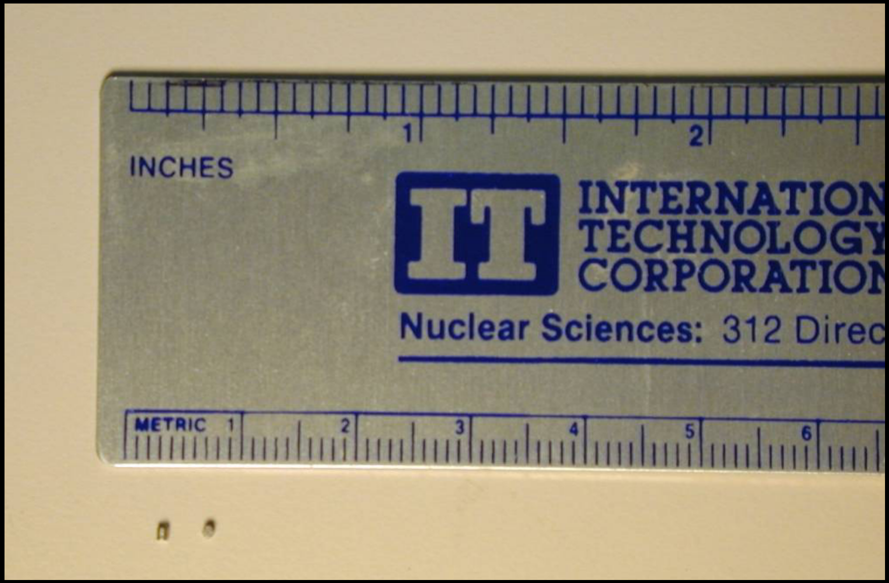
Model 4C Collimator/Helmet



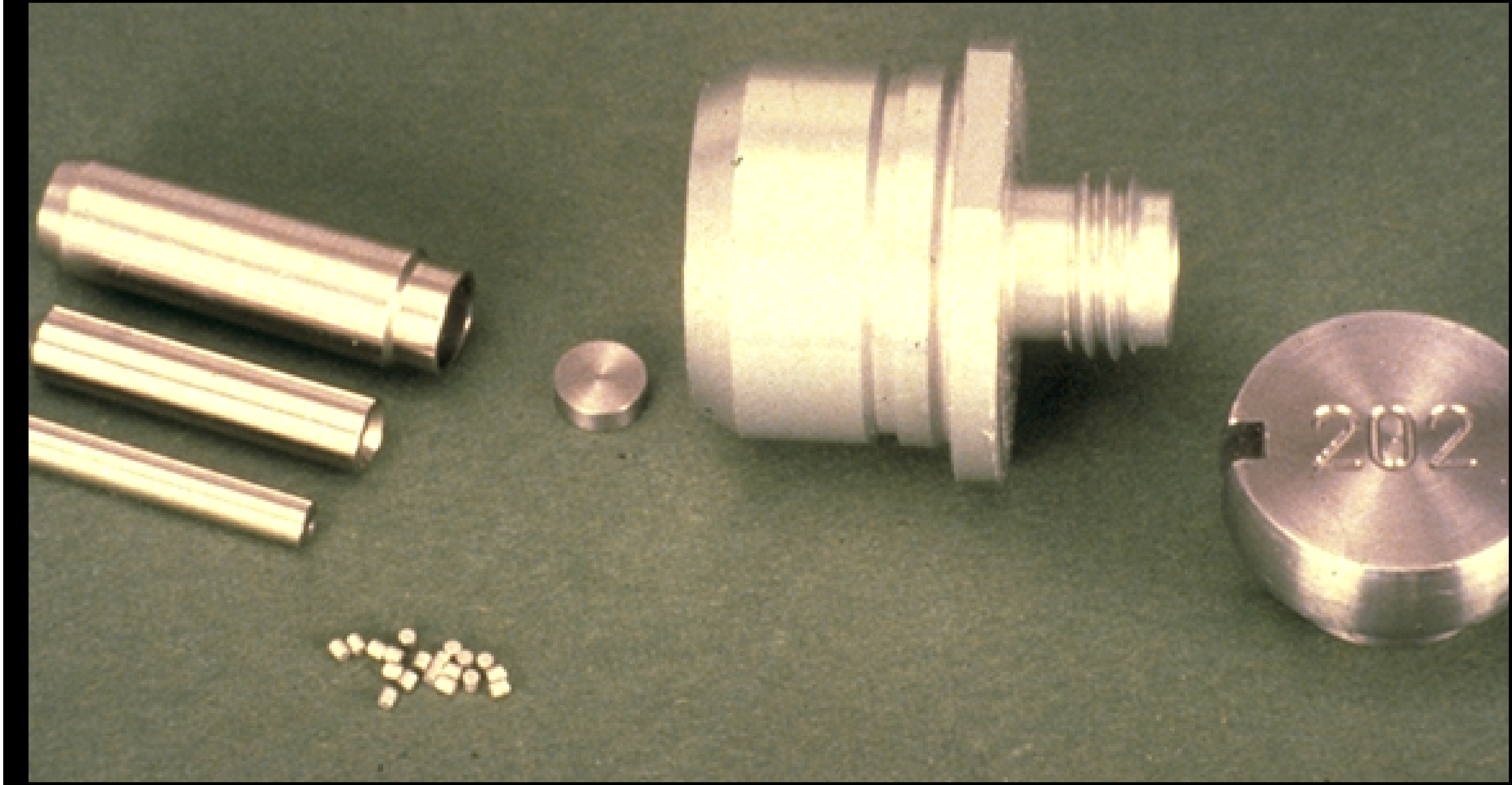
The head is positioned within the Gamma Knife so that the tumor is in the focal point of the 201 gamma rays. The gamma rays pass through the holes in the collimator. There are 4 collimator sizes and the treatment is stopped when the collimator needs to be changed.

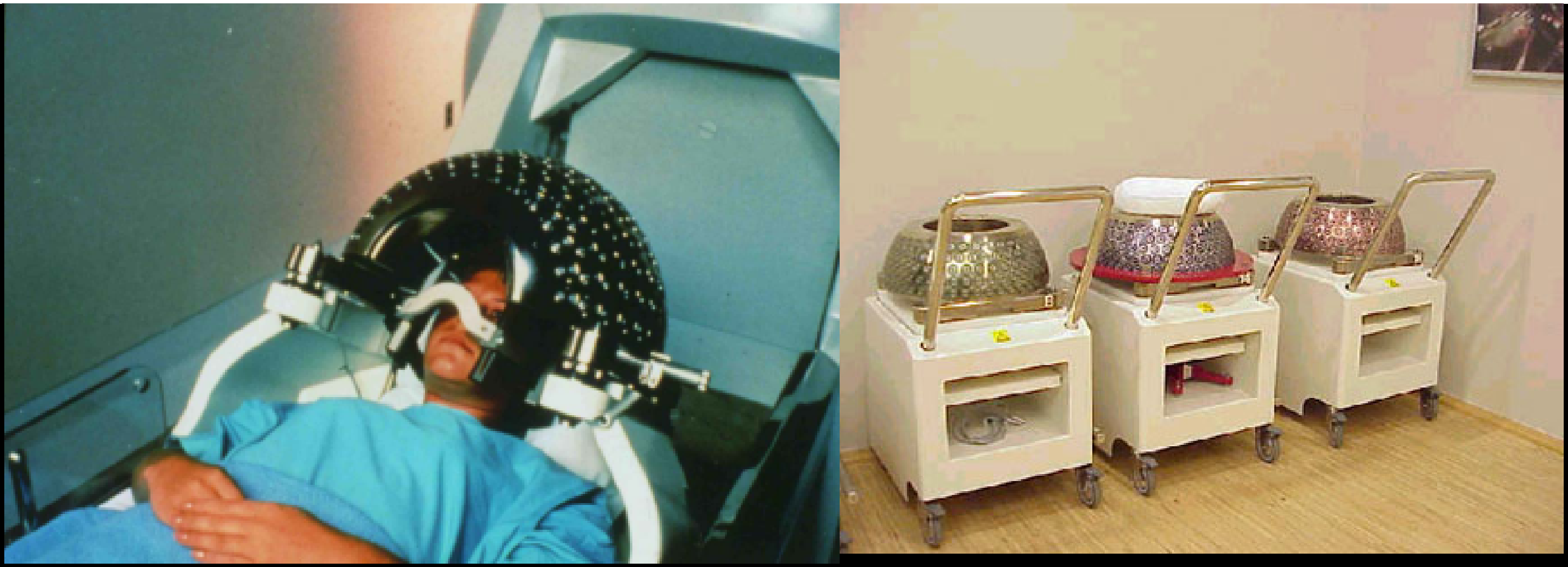
Comparison of Gamma Knife Treatment Units

The same sources are used for both models:

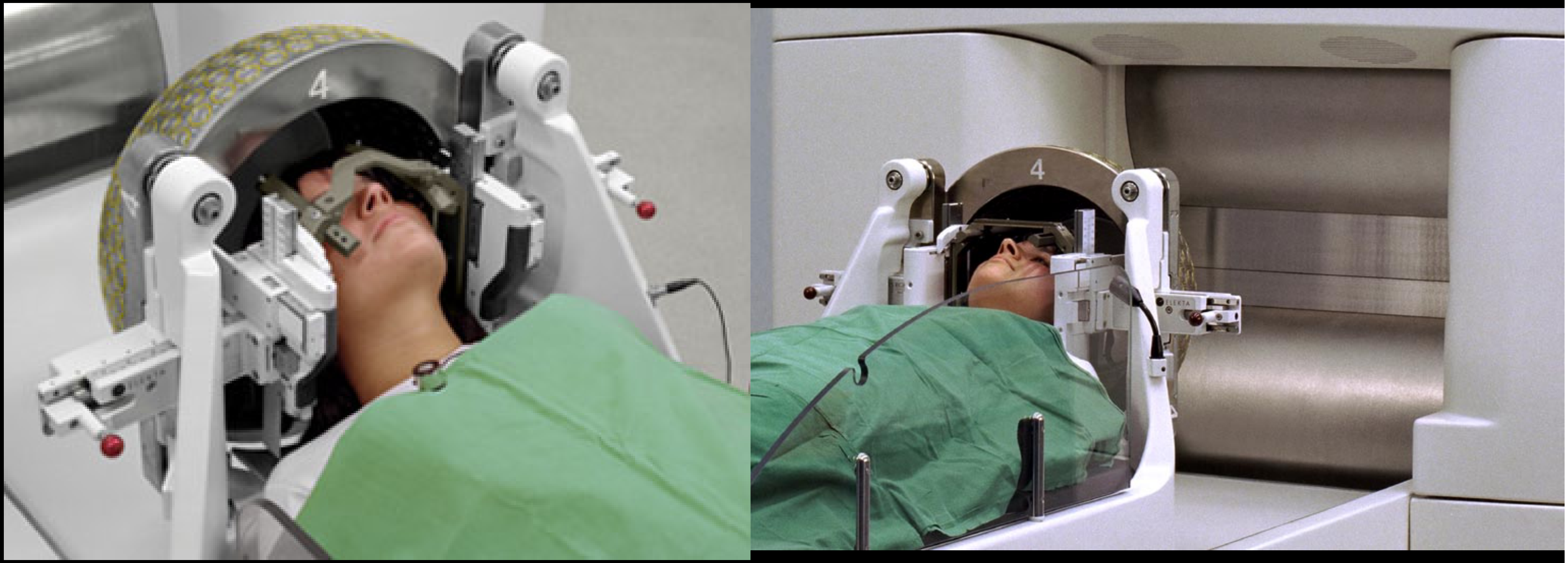


- “Seeds” of 1 mm diameter
- Cobalt-60
- 192 or 201 sources

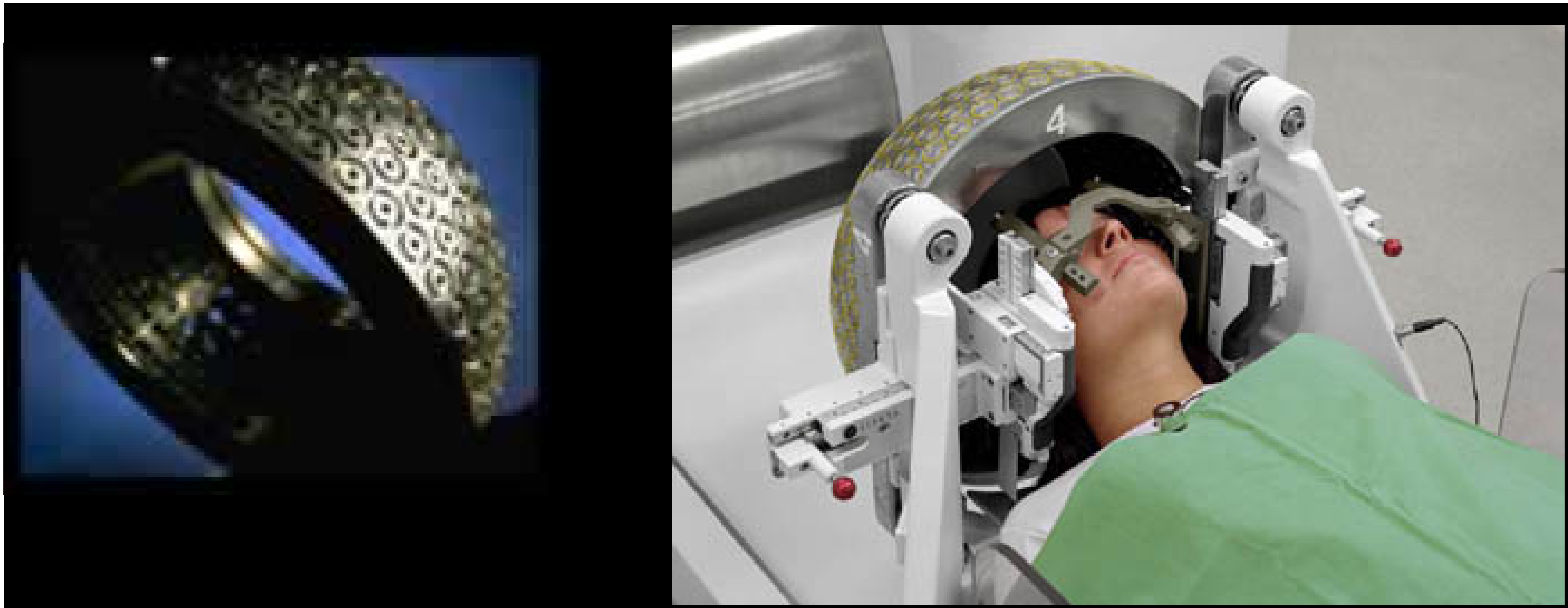

202



The patient lies on the treatment table of the gamma knife while the frame is affixed to the appropriate collimator which determines the size of the treatment.



The head is positioned within the Gamma Knife so that the tumor is in the focal point of the gamma rays.



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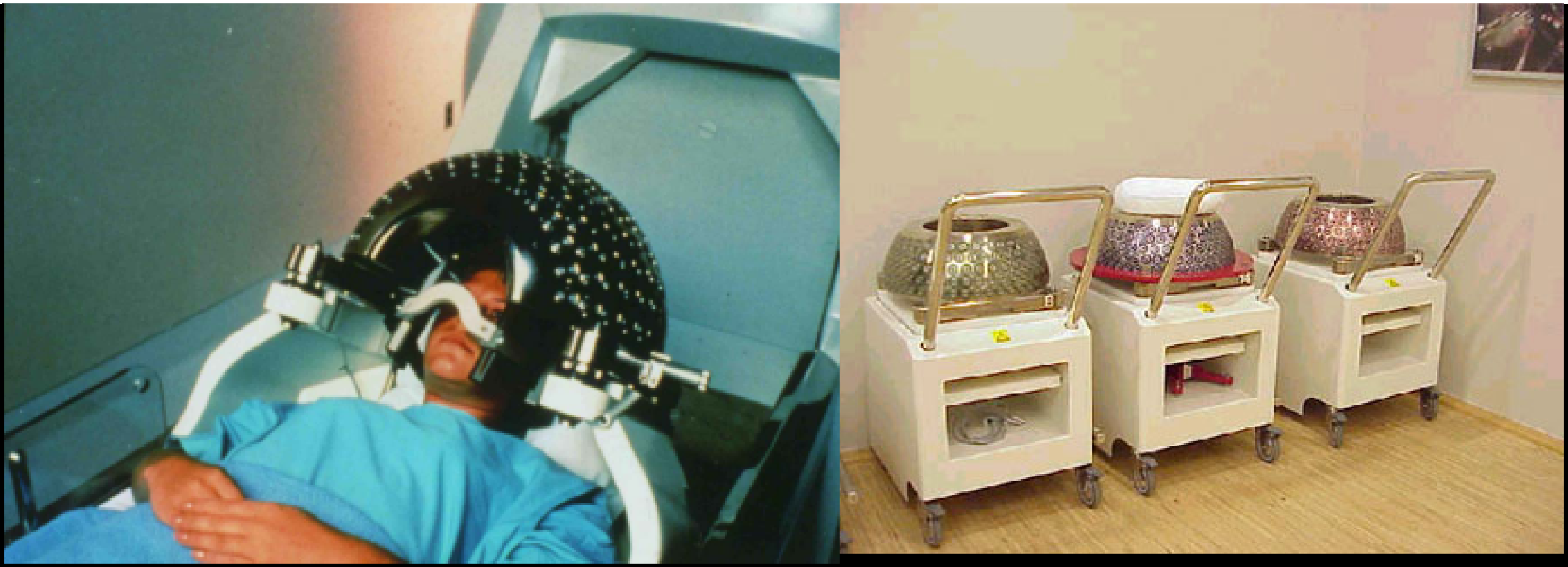

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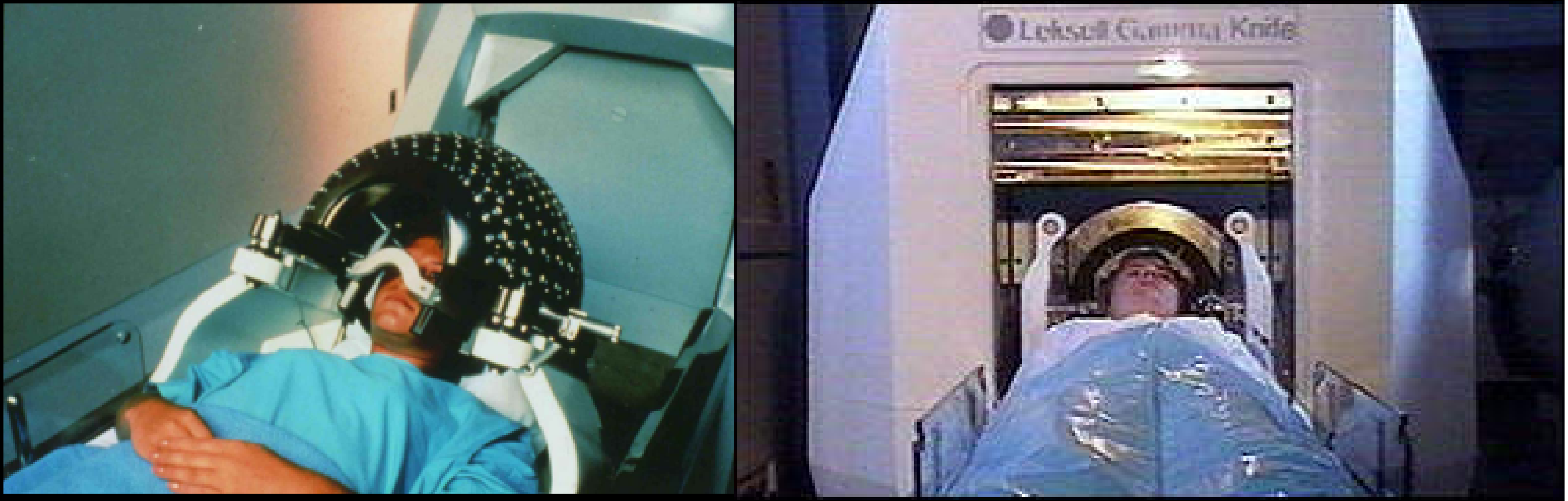


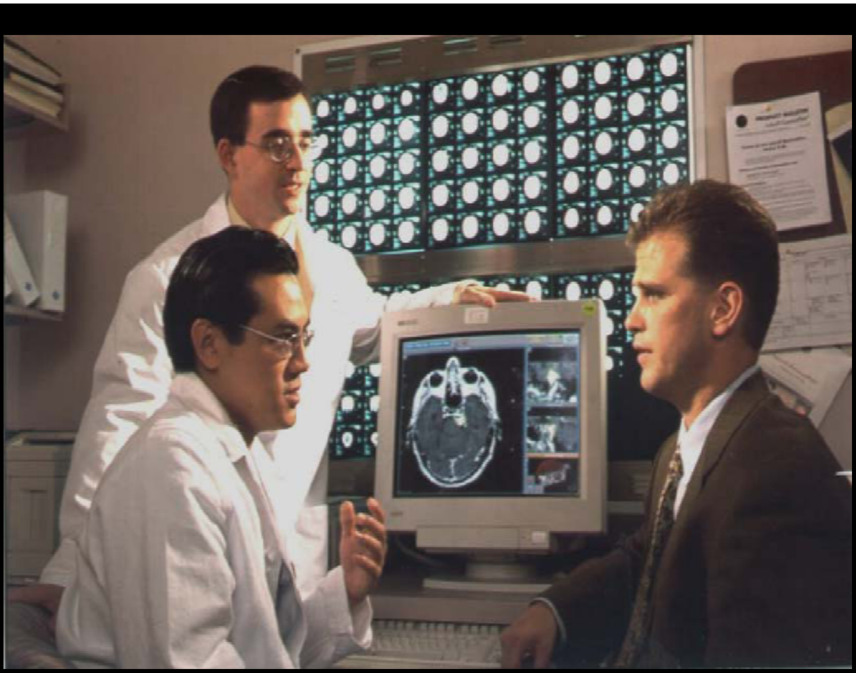
The door to the treatment unit opens. The patient is advanced into the shielded treatment vault. The area where all of the beams intersect is treated with a high dose of radiation.

The table is moved into the Gamma Knife where the patient rests for a few minutes during each painless treatment.

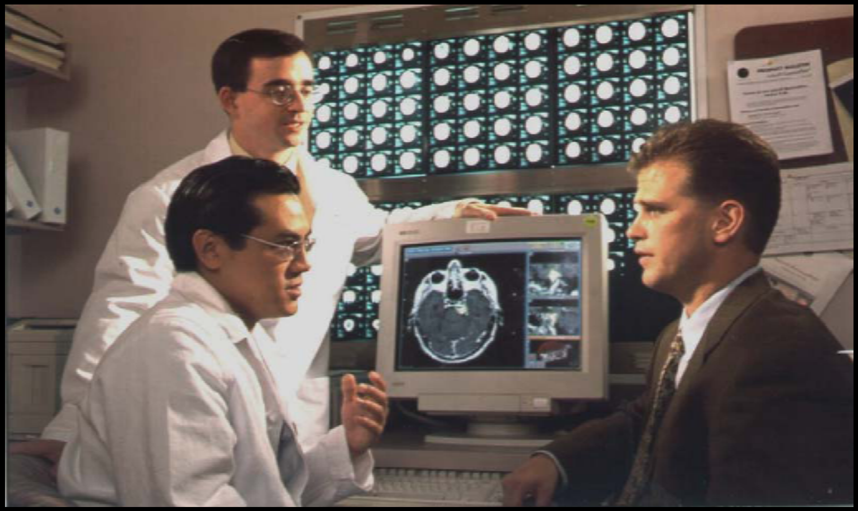
Movement of the treatment table in and out of the radiation unit, and opening of the shielding door as performed by the hydraulic or electrical power system, are the only sources of movement during the procedure.

Usually more than one treatment is given to completely cover the target. Between each treatment the patient is moved out of the Gamma Knife so minor adjustments to the stereotactic coordinates and collimator can be made.

After Gamma Knife surgery the head frame is removed and the patient returns home to rest or rests overnight in the hospital.

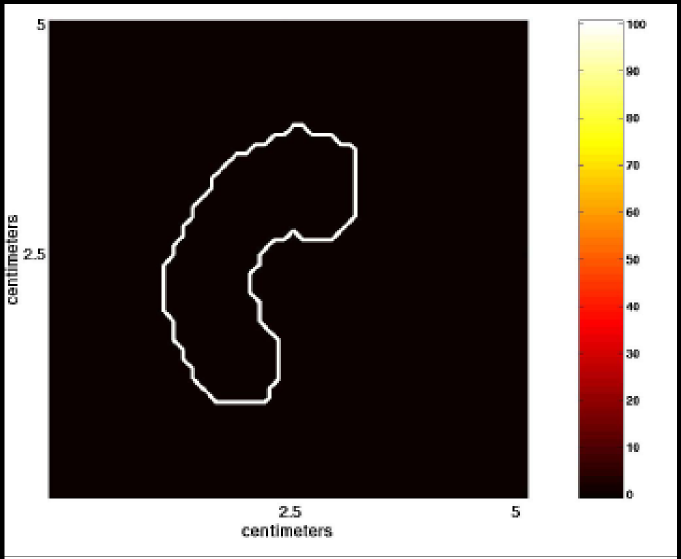


The treatment plan is developed by computer using brain images. This is done with the coordinated efforts of the neurosurgeon, radiation oncologist, and radiation physicist.

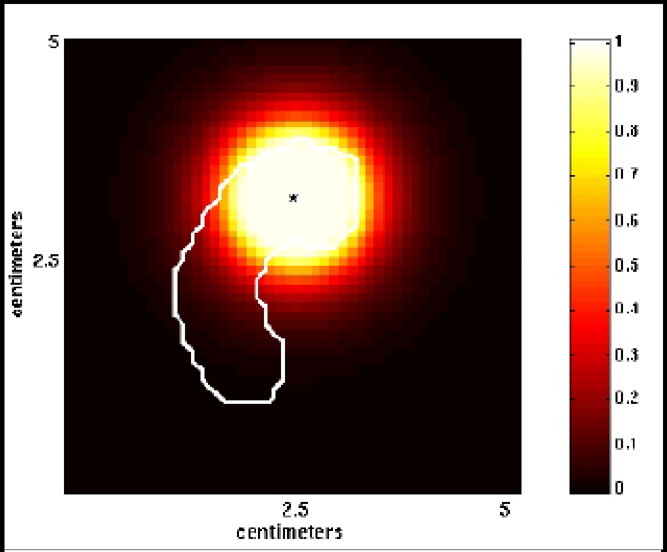


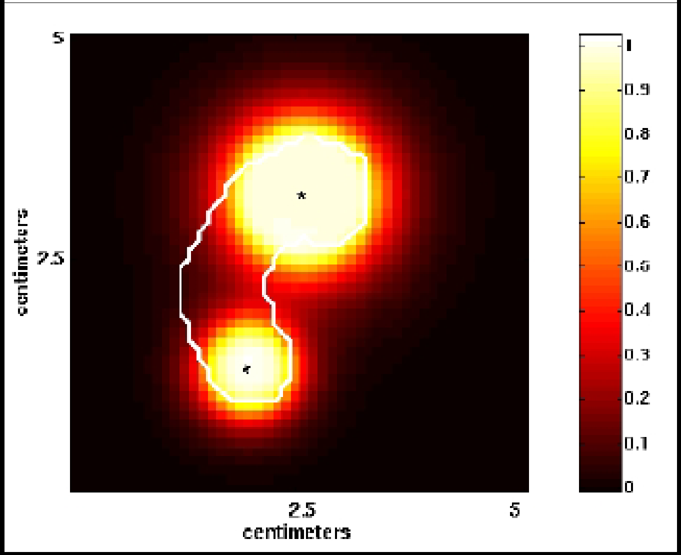
Through an iterative approach the following parameters are determined:
– the number of shots
– the shot sizes
– the shot locations
– the shot weights

TARGET

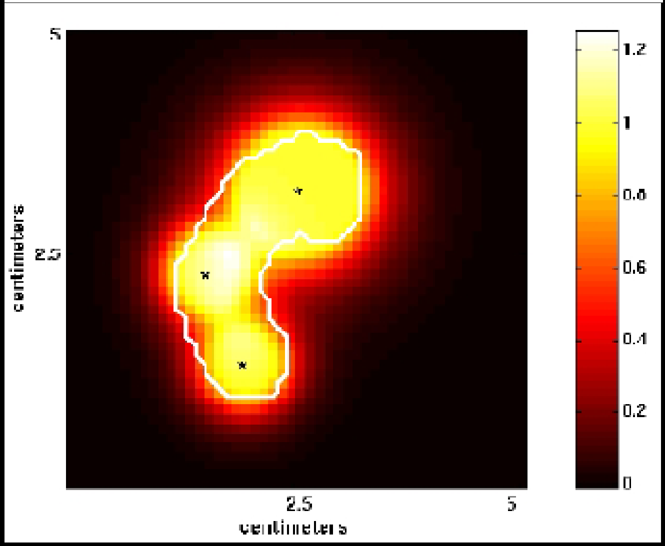


SHOT 1

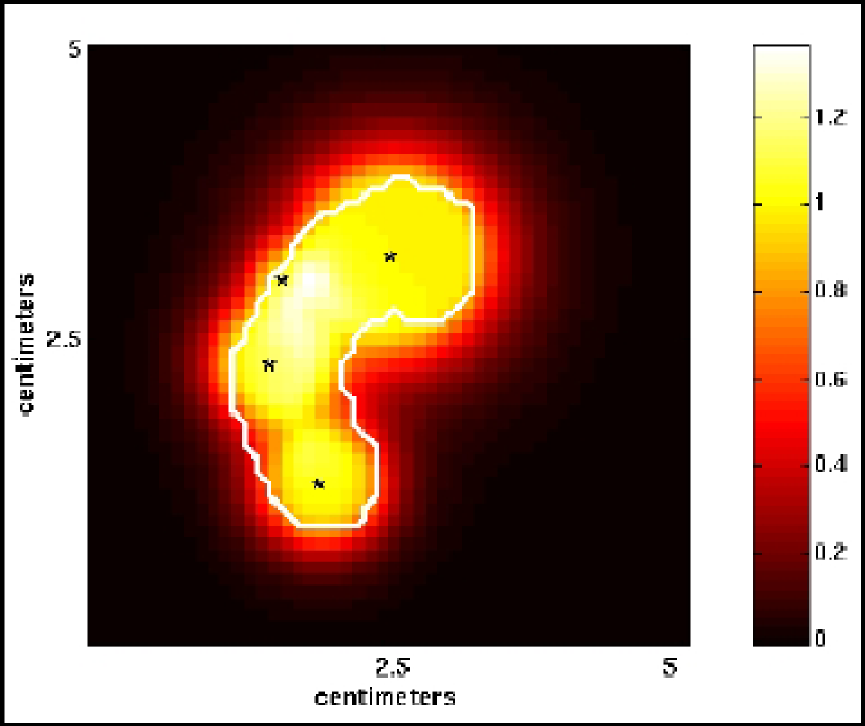


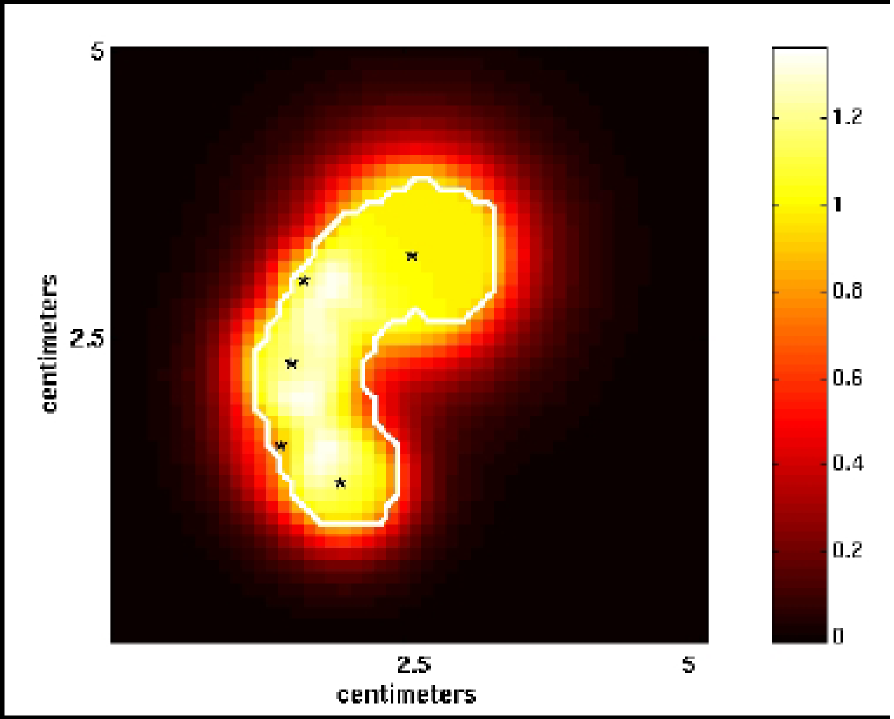


SHOTS 2



SHOTS 3





SHOTS 4

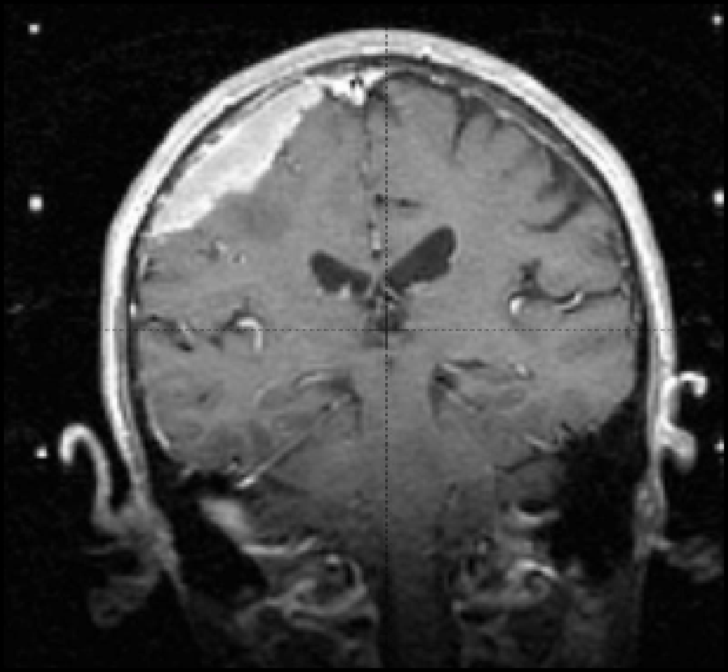
SHOTS 5

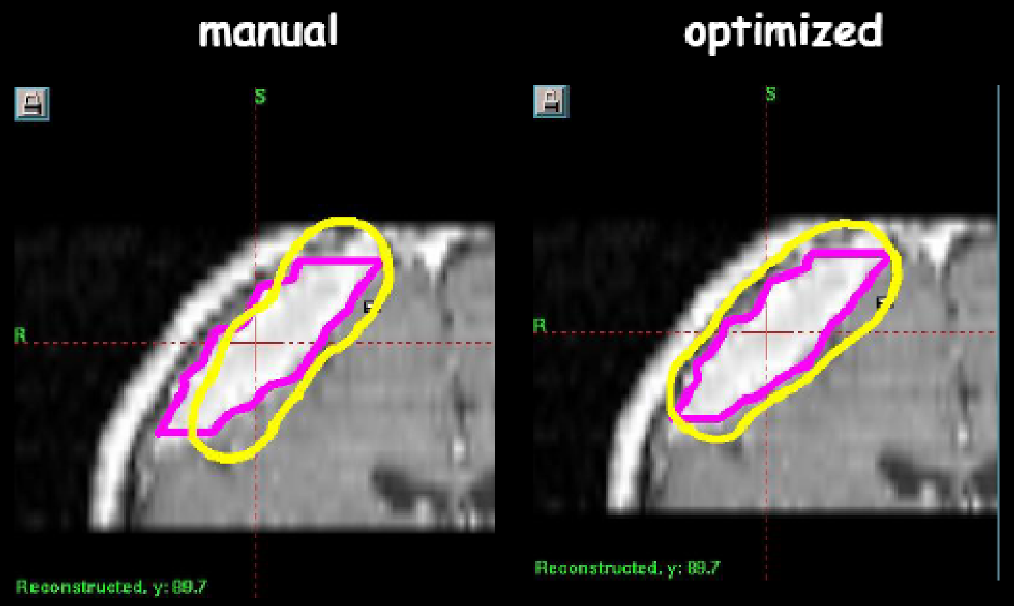
Automated Planning

- Develop a fully automated approach to Gamma Knife treatment planning
- Better tumor dose coverage
- Reduced dose to normal tissue
- More efficient treatments
- Reduced time commitment for neurosurgeon

Computational Model

- Target volume (from MRI or CT)
- Maximum number of shots to use
  - Which size shots to use
  - Where to place shots
  - How long to deliver the shot
  - Conform to Target (50% isodose curve)
  - Real-time optimization




manual
optimized
S
R
Reconstructed, y: 89.7
S
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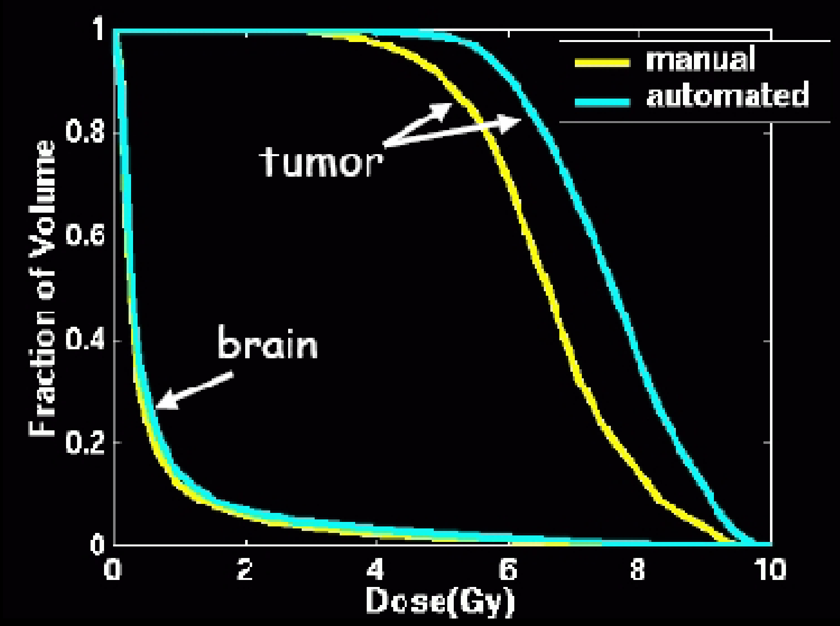
manual
automated
tumor
brain
Fraction of Volume
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0.6
0.8
1
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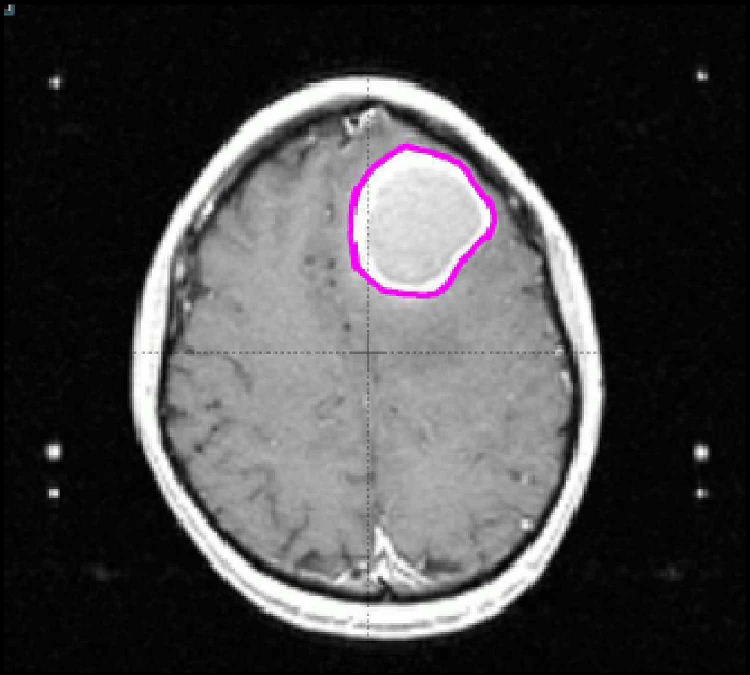
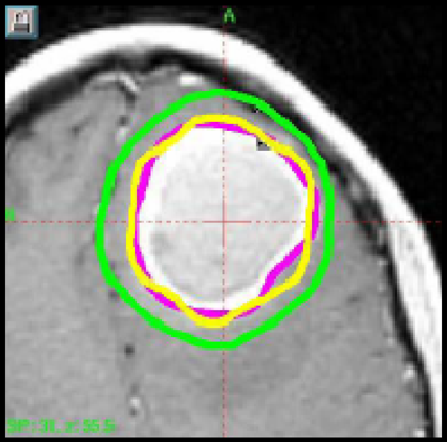
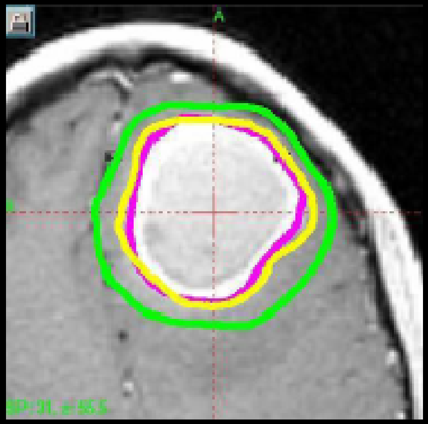
2
4
6
8
10
Dose(Gy)

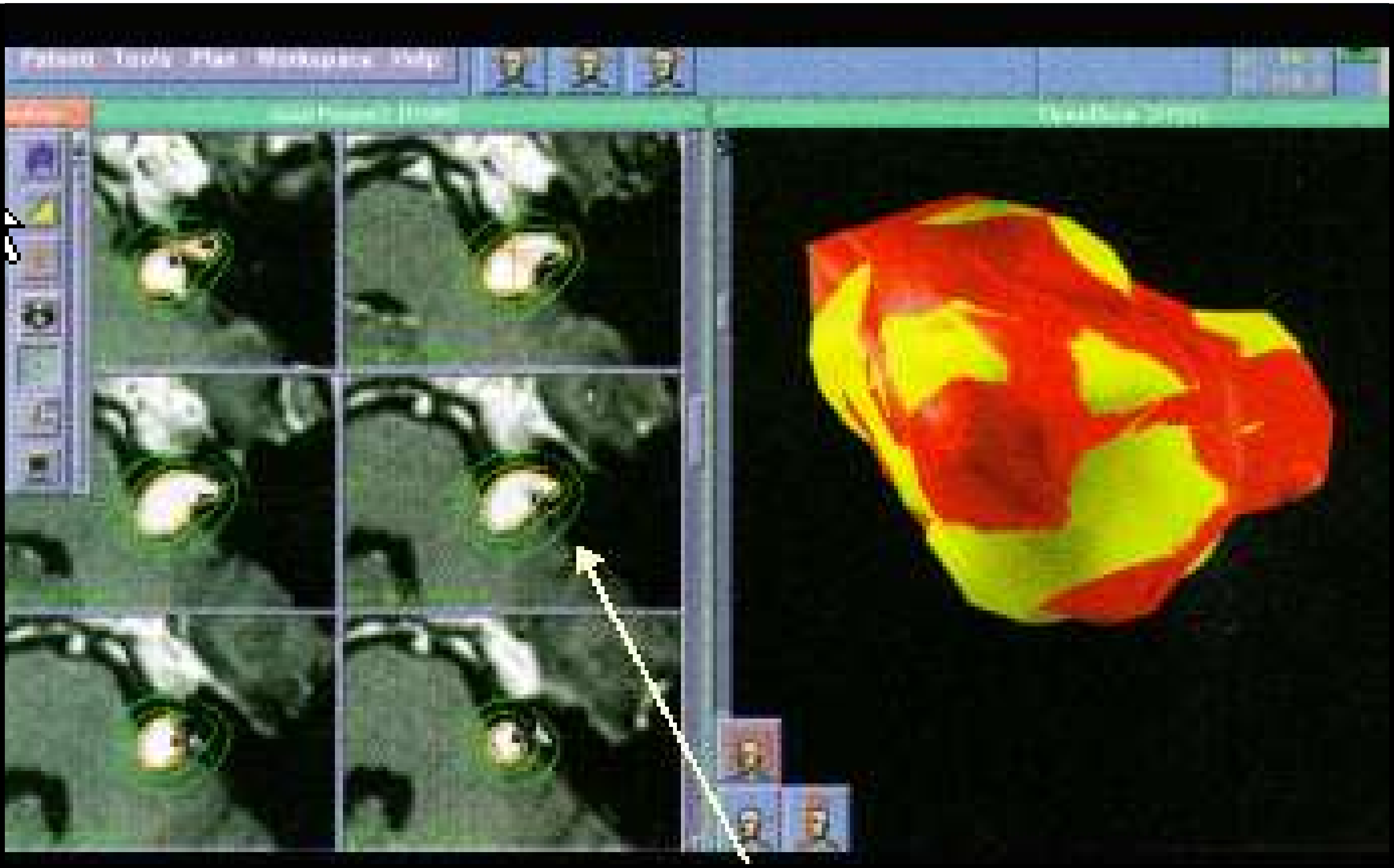




15 shot manual



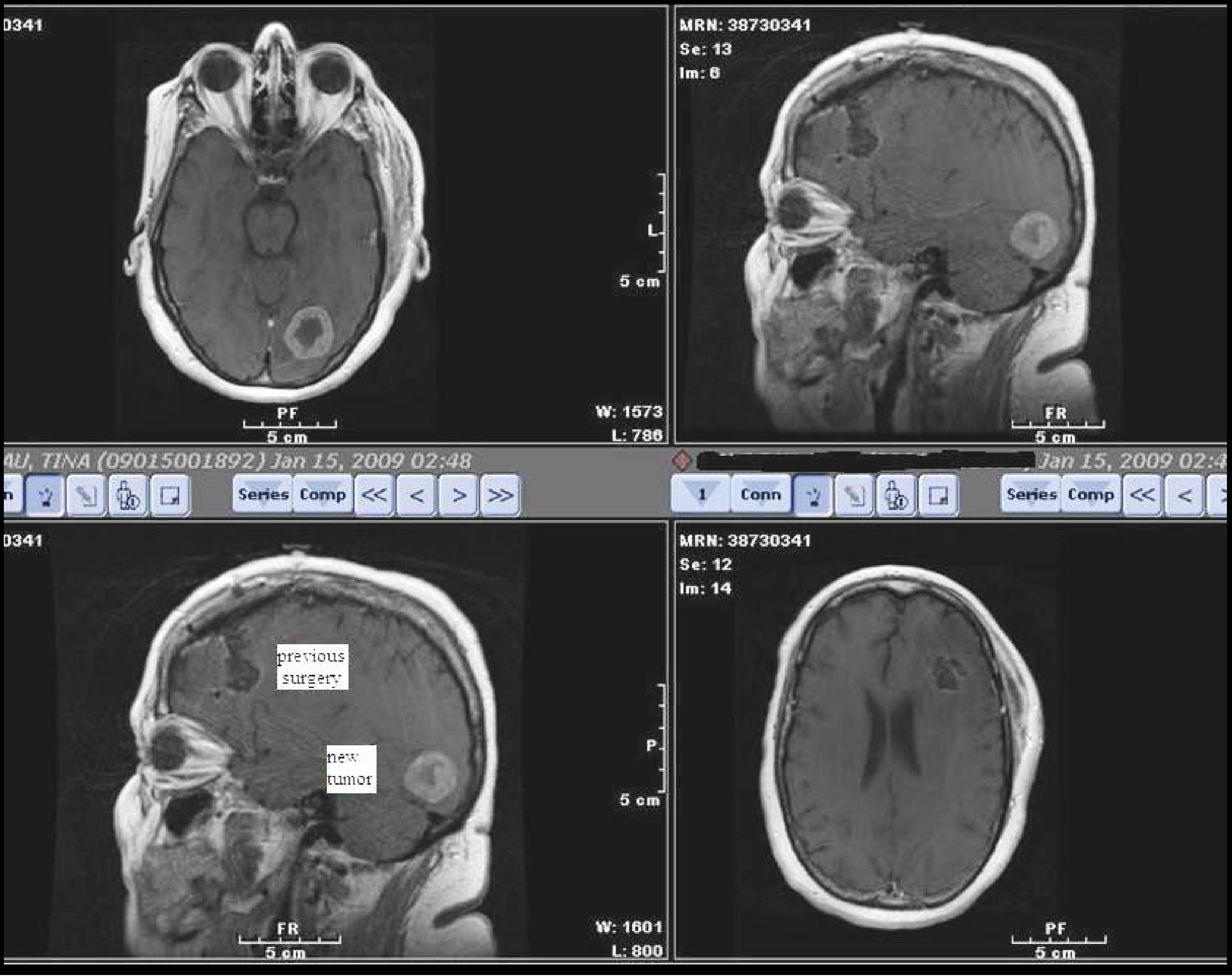
12 shot optimized



The completed plan outlines the gamma ray dose and location within the brain for each treatment.

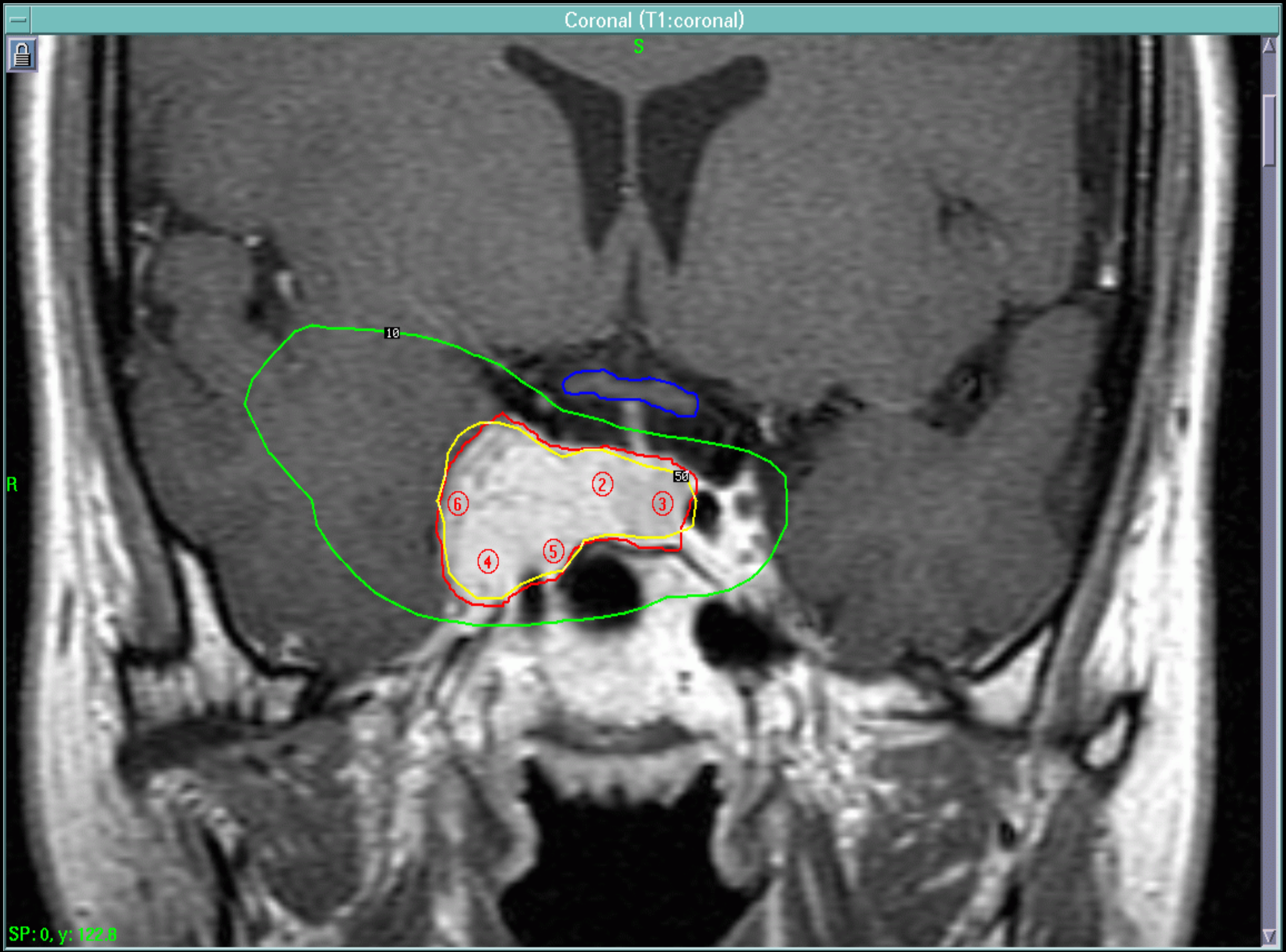
Interesting Gamma Knife Surgery Case Presentations

Gamma Knife Radiosurgery

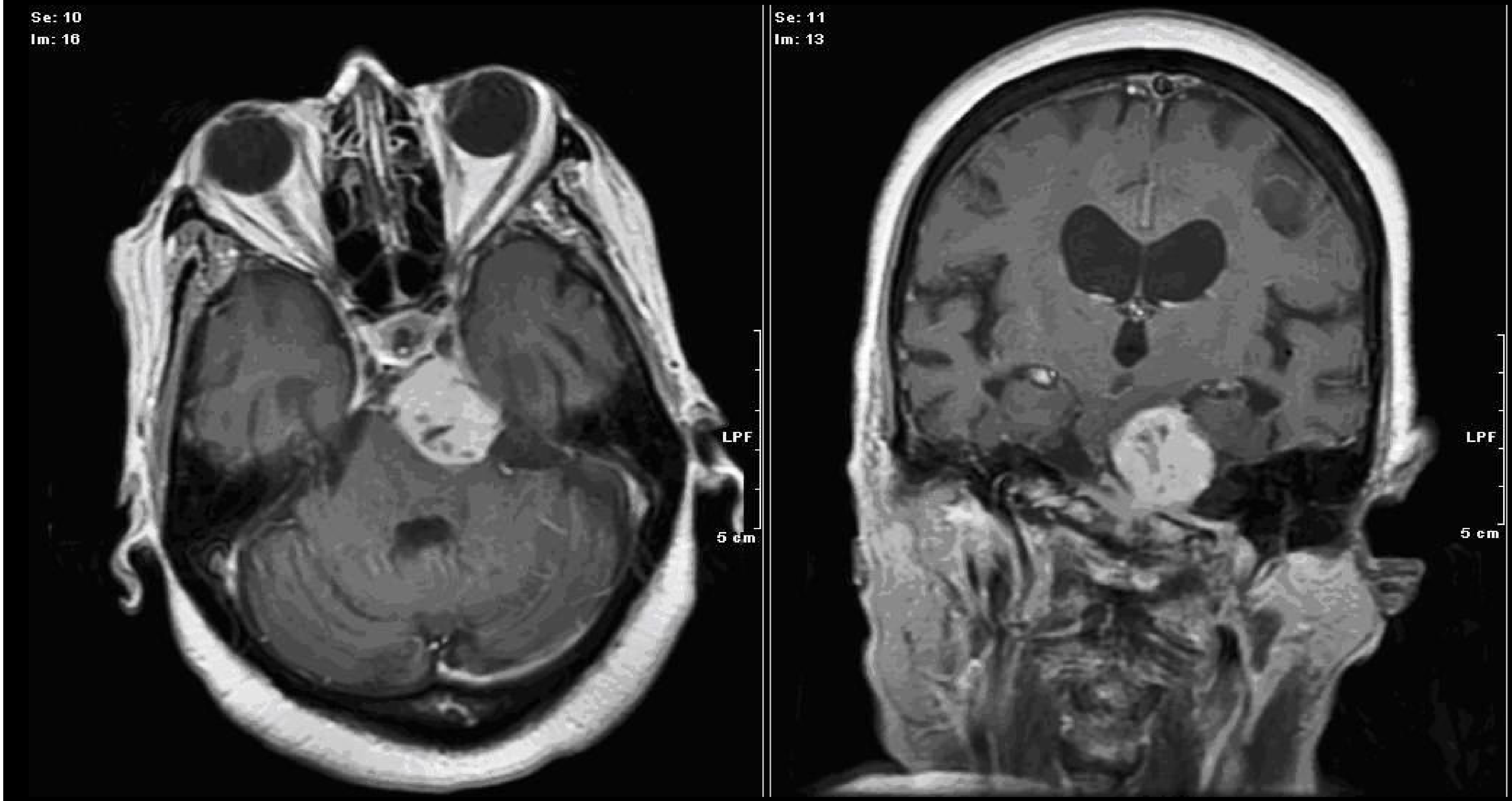


Before Treatment: New metastatic lesion presents after craniotomy

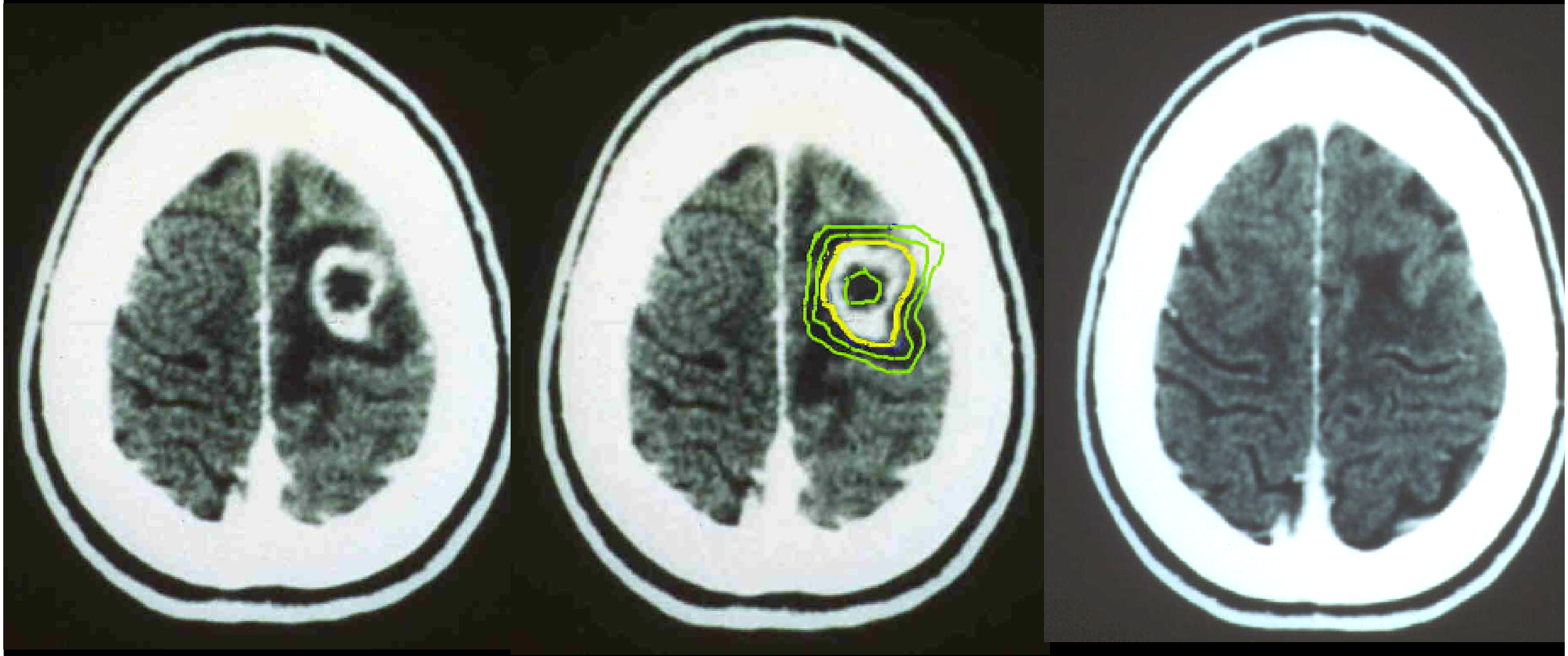
Meningioma



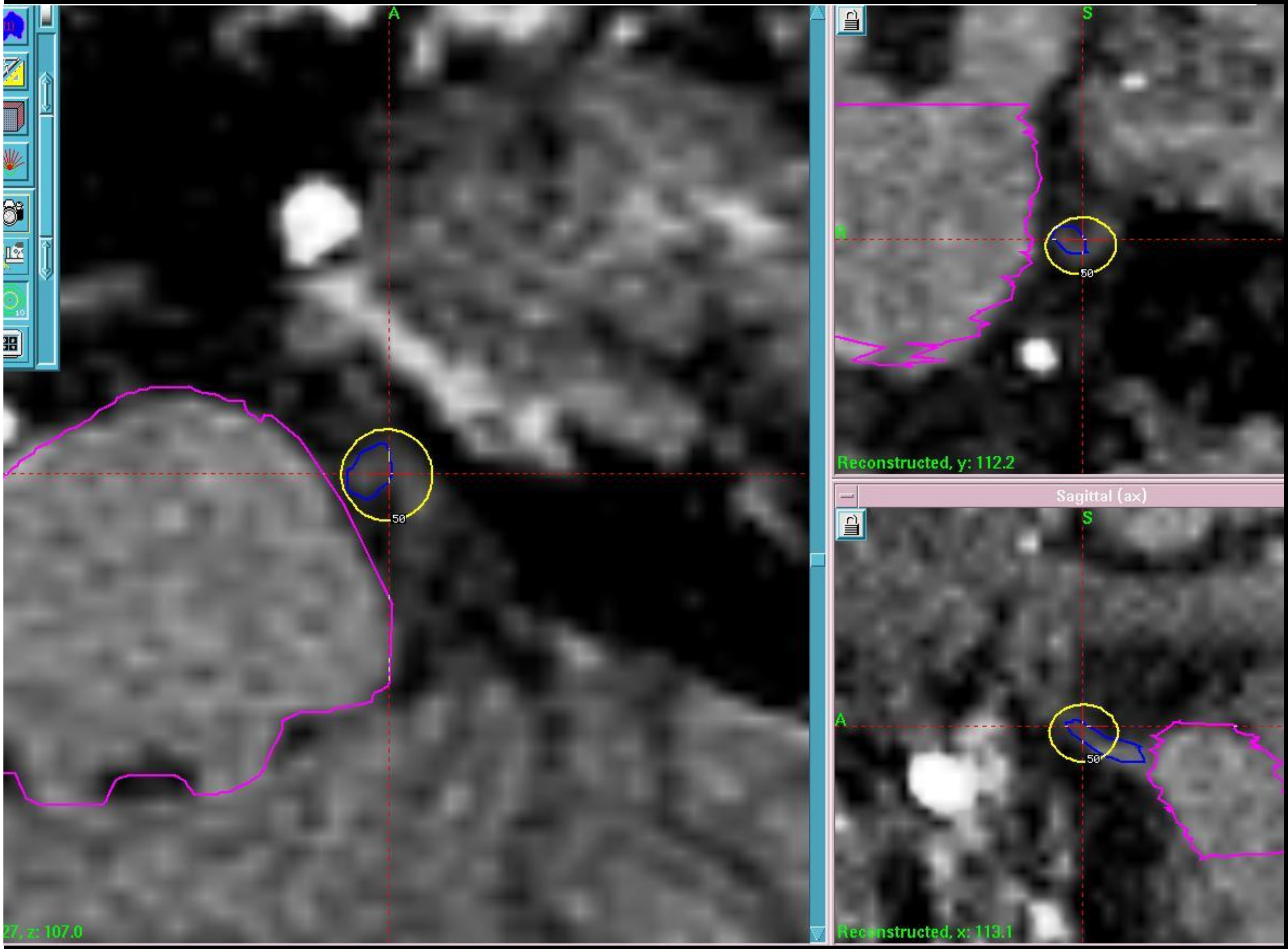
Gamma Knife Radiosurgery



Gamma Knife Radiosurgery



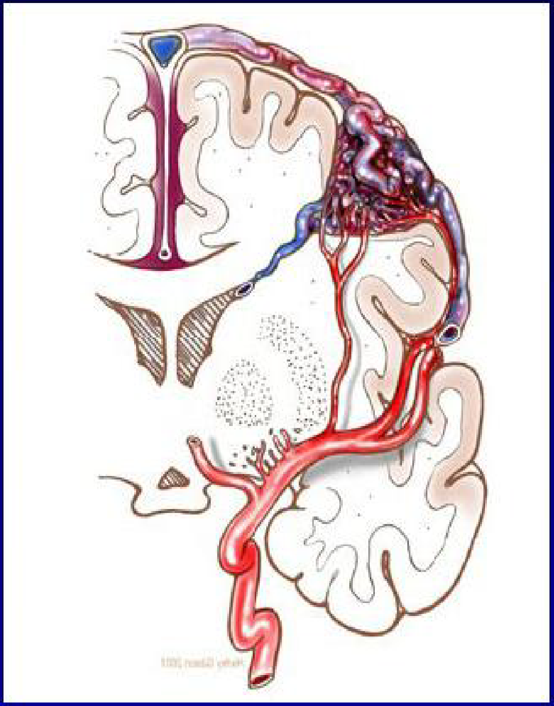
Gamma Knife Radiosurgery

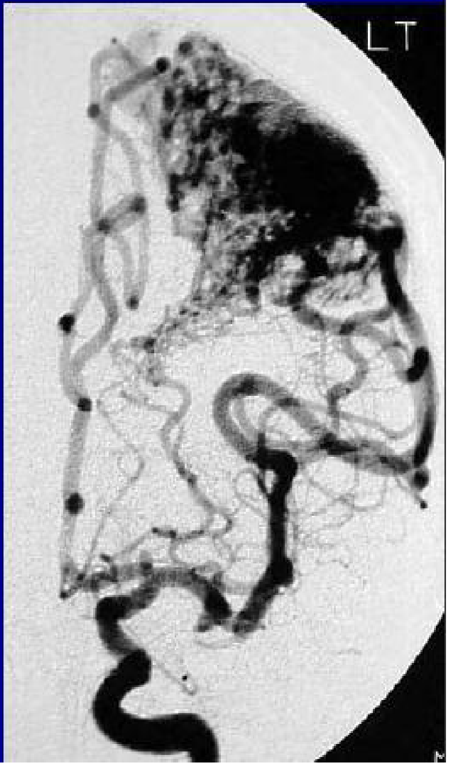


Trigeminal nerve in blue and brainstem in pink. The delivered dose is in yellow.

Natural History of AVM's

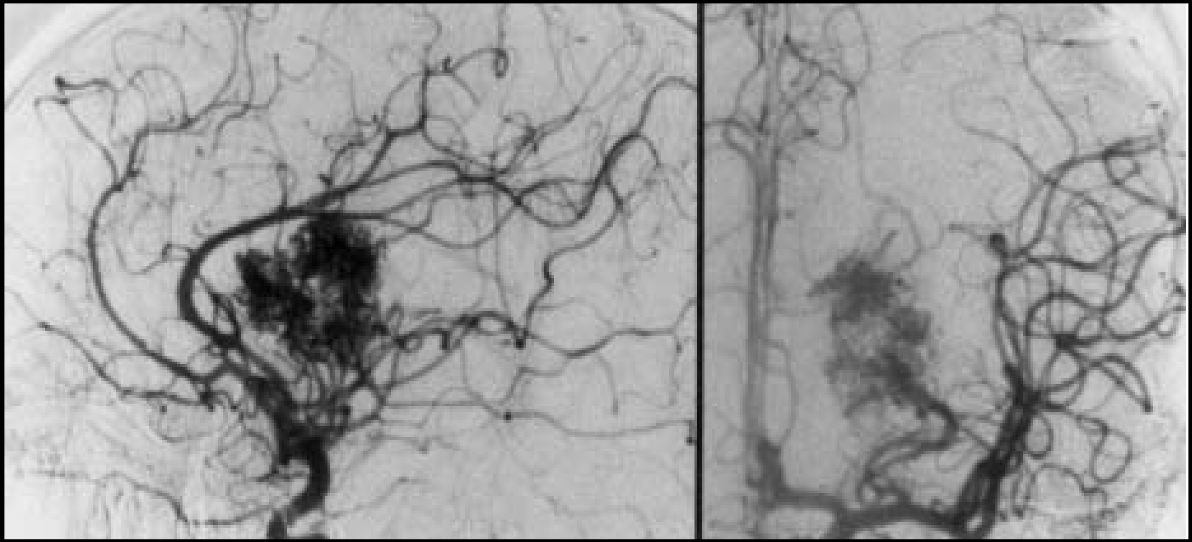
- 2-4% annual risk of bleeding dependent in part on
  - AVM size
  - Location
  - Prior bleeding
  - Patient Age
- Lifetime risk of hemorrhage(%) = 105-patient's age (years)
- 3% combined annual morbidity/mortality



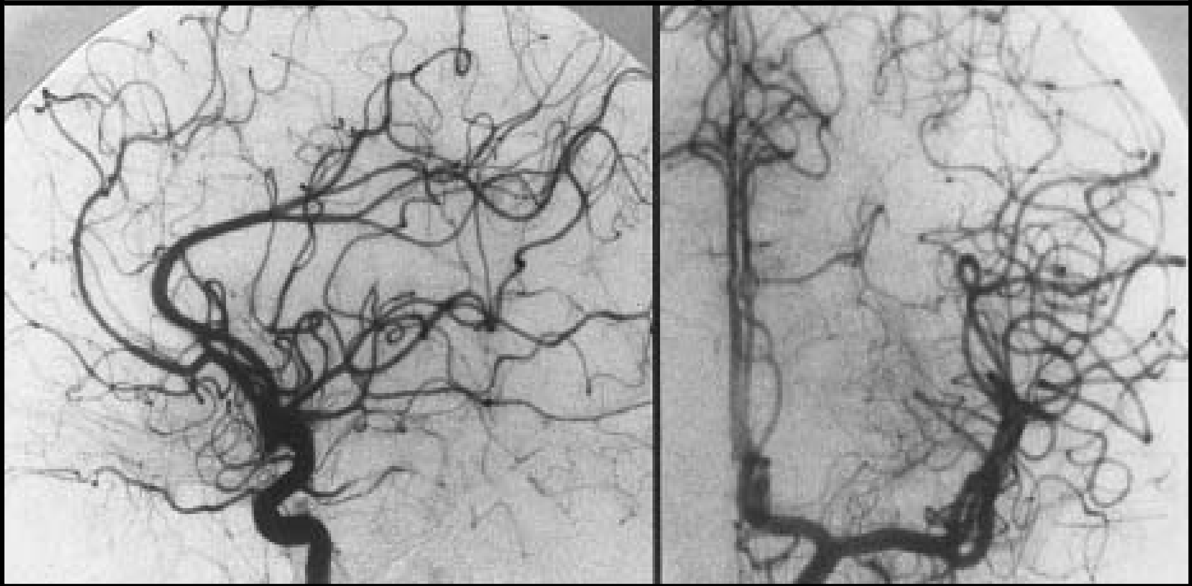


Arteriovenous malformation

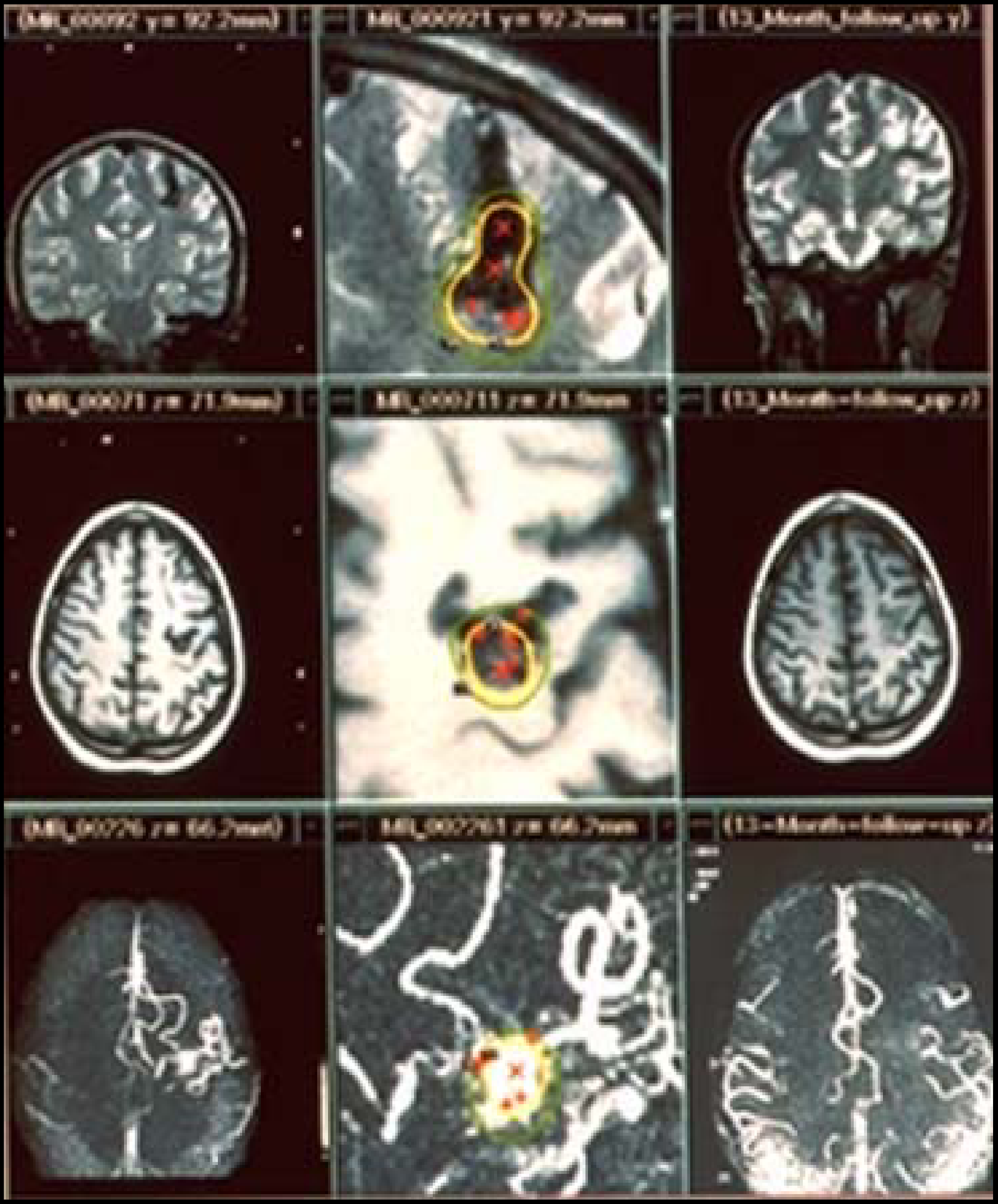
Pre Gamma Knife® surgery



2 years post Gamma Knife® surgery



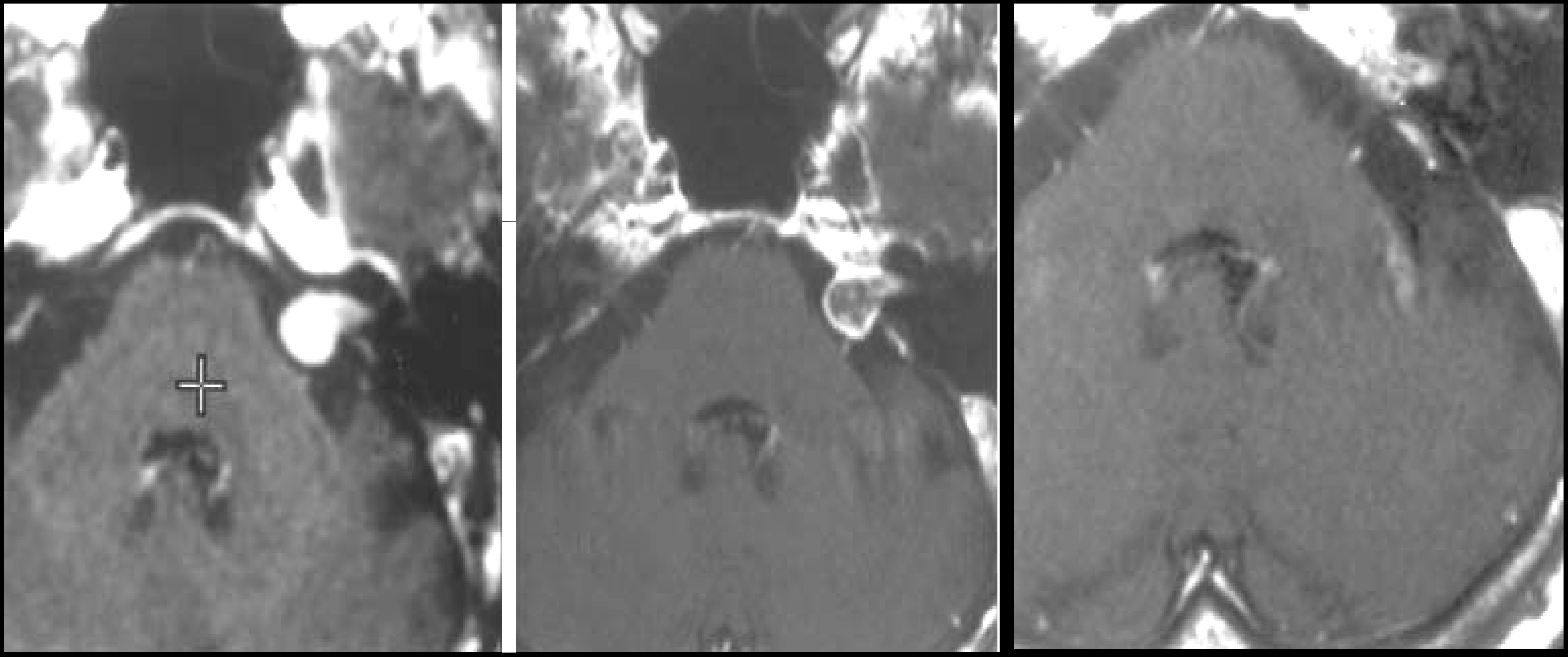
AVM



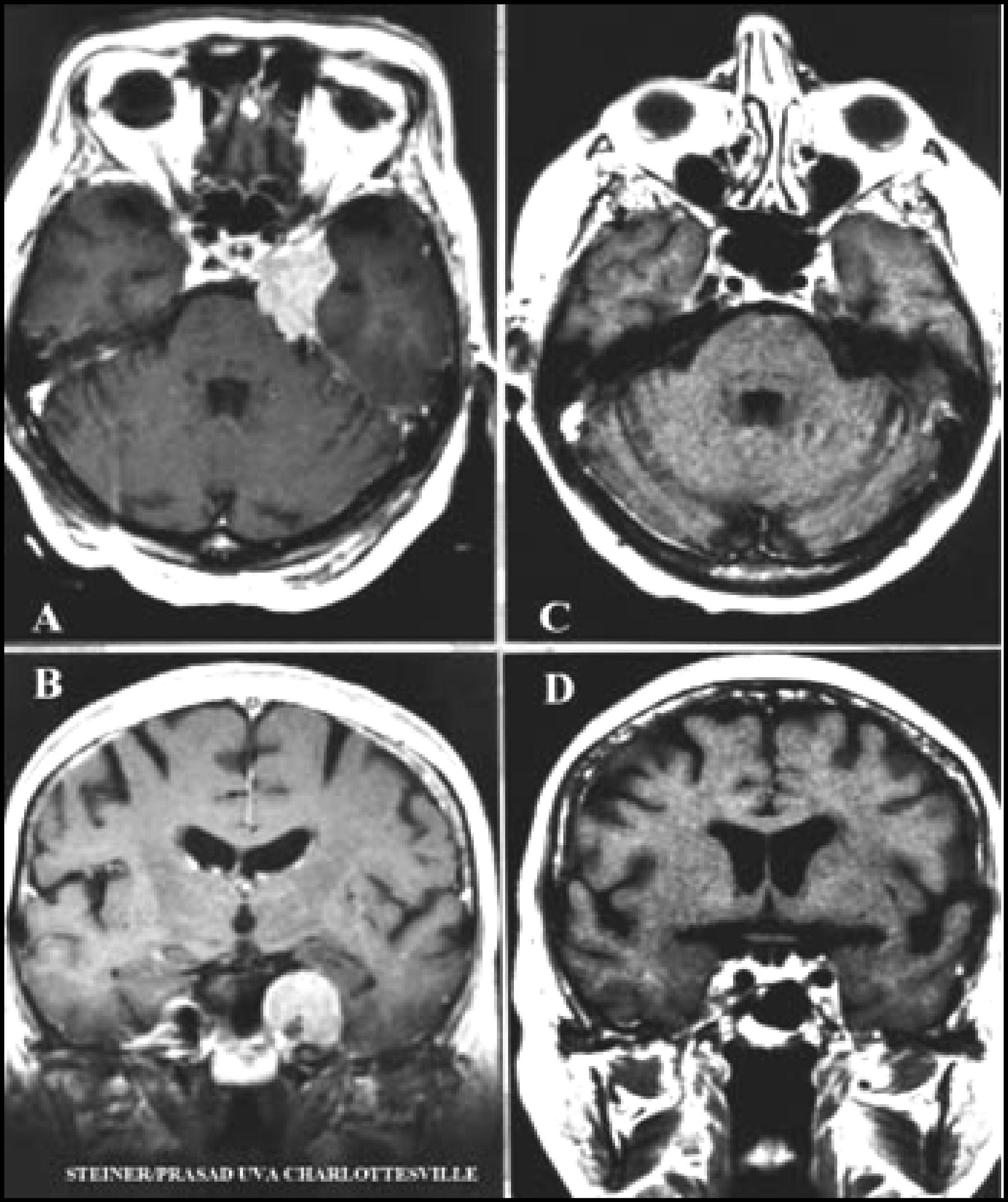
Pre treatment

13 months
post treatment

Acoustic Neuroma



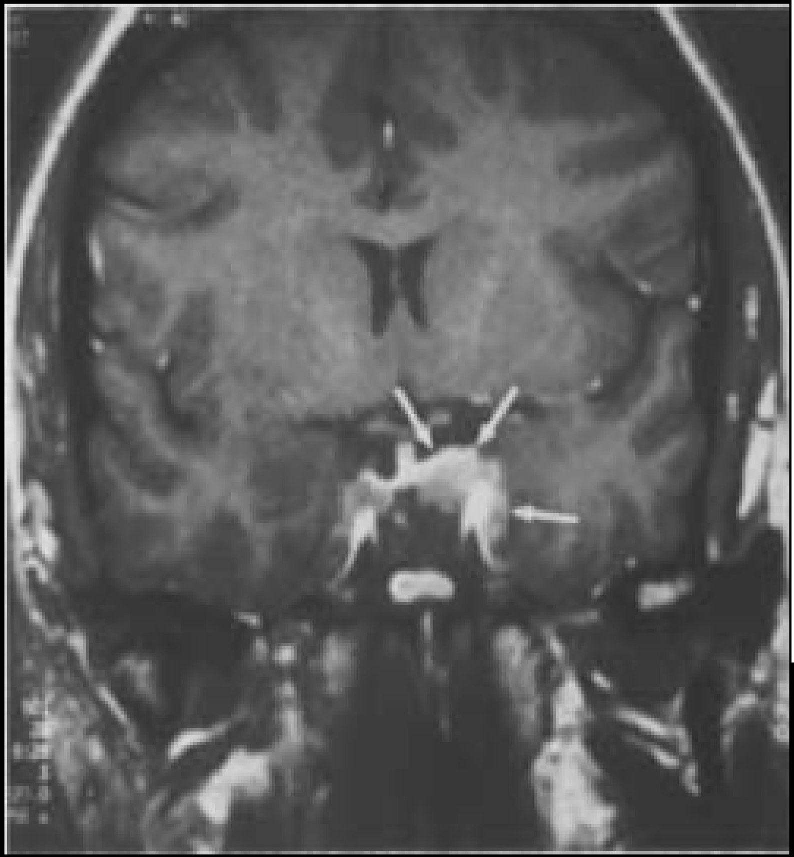
Meningioma



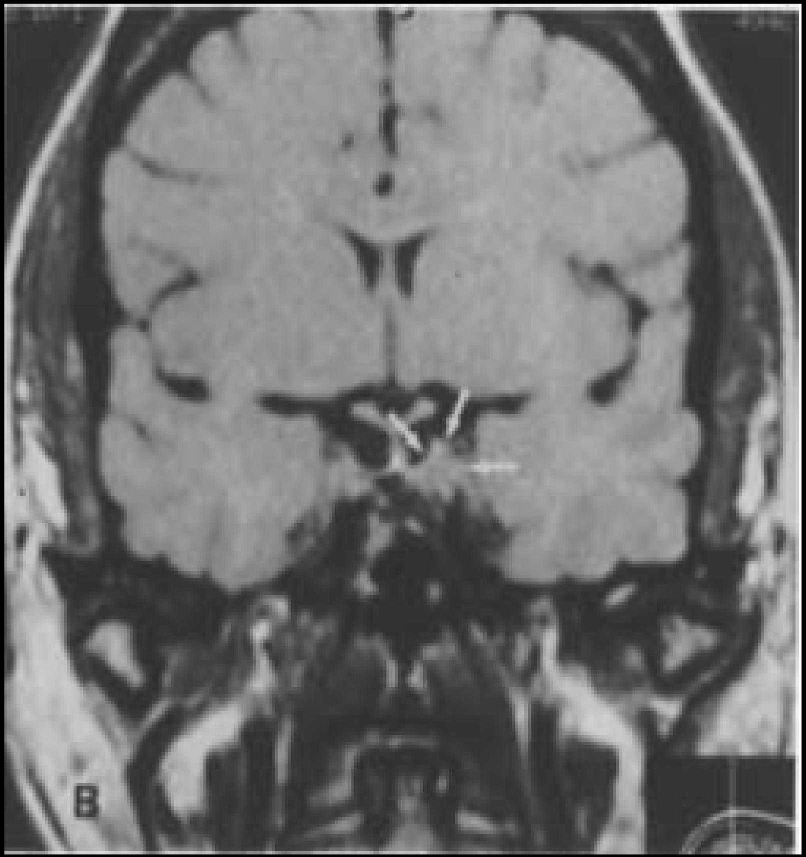
Courtesy: Ladislau Steiner, MD,
PhD and Dheerendra Prasad, MD
UVA Charlottesville, USA

Pituitary Adenoma

Courtesy: Ladislau Steiner, MD, PhD, UVA Charlottesville, USA
and Christer Lindquist, MD, PhD, Karolinska Institute, Sweden

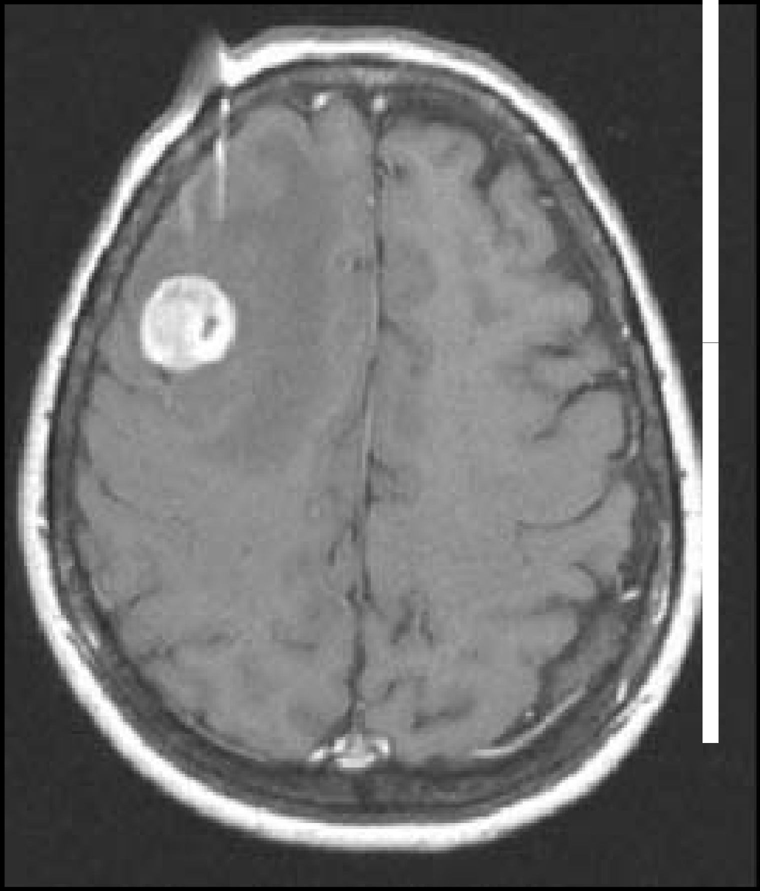


Pre treatment



54 months post treatment

Metastasis



Pre treatment

10 months post treatment

Metastatic Tumor

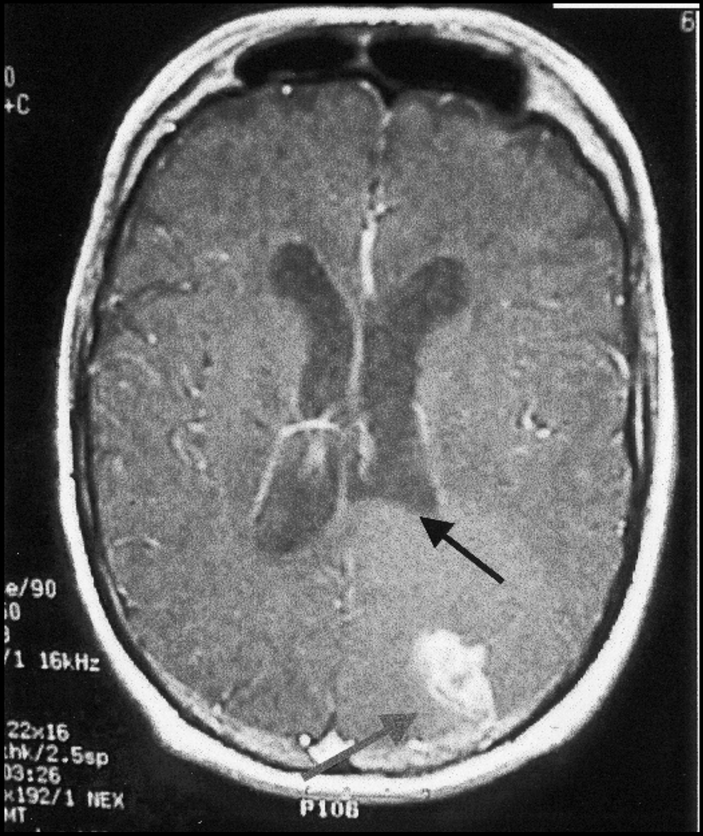


Figure A

Male, 65 years old, metastatic tumor of lung cancer origin. Pre-Gamma Knife®. Tumor + mass effect (compression of lateral ventricle)

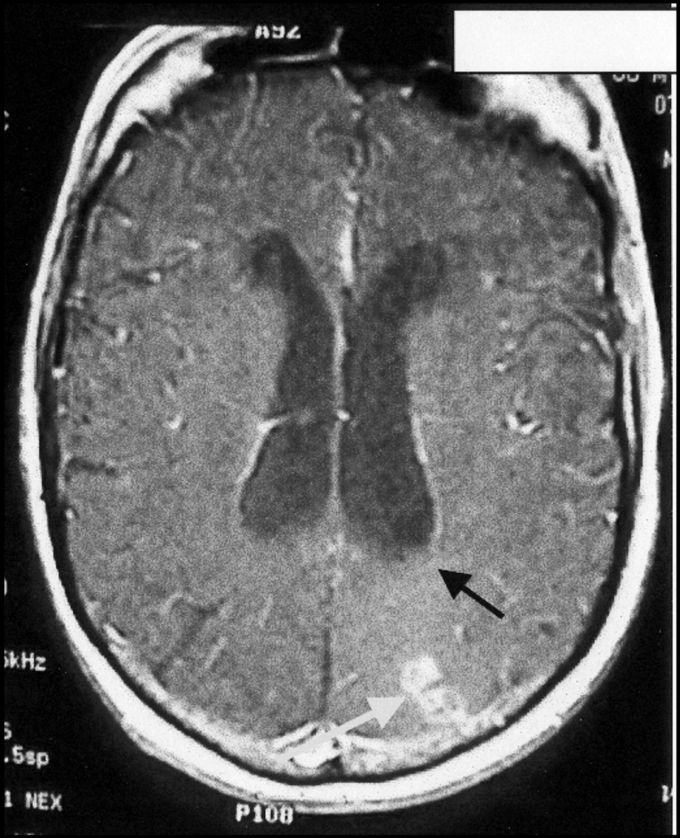
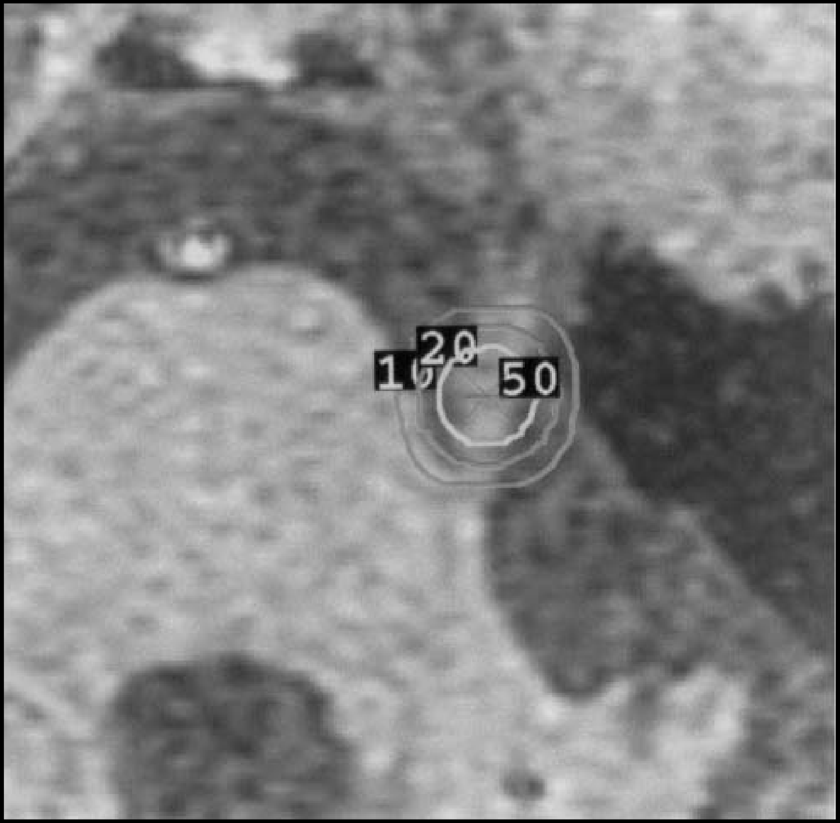


Figure B

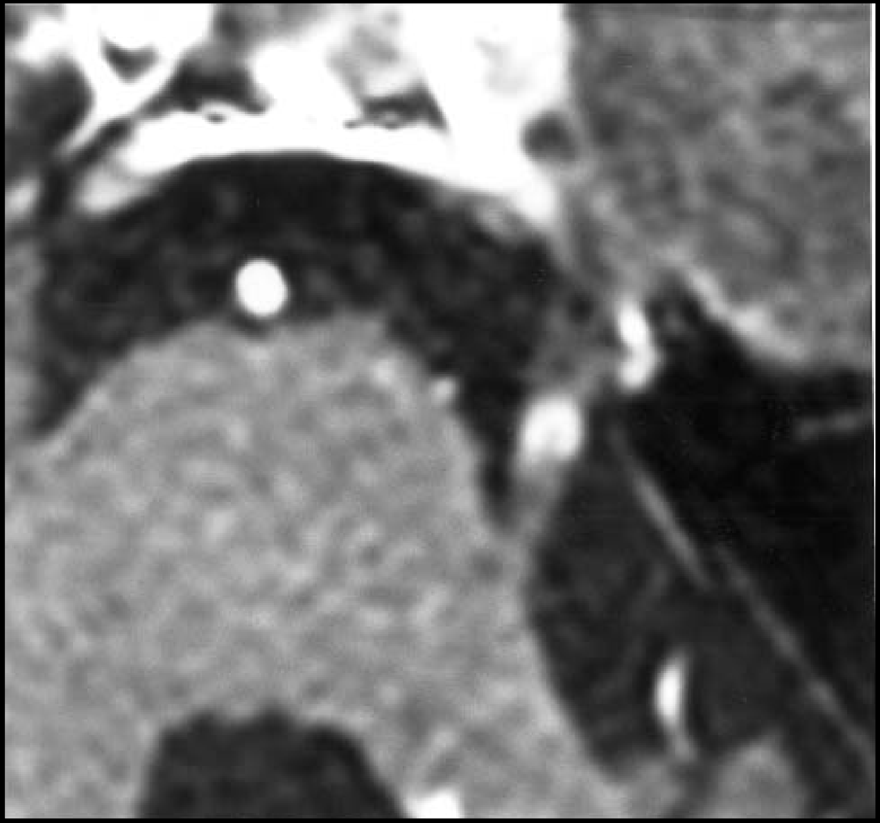
6 weeks Post Gamma Knife®. Tumor volume and mass effect reduced.

Trigeminal Neuralgia

Courtesy: Douglas Kondziolka, MD, MSc, FRSC, University of Pittsburgh, USA

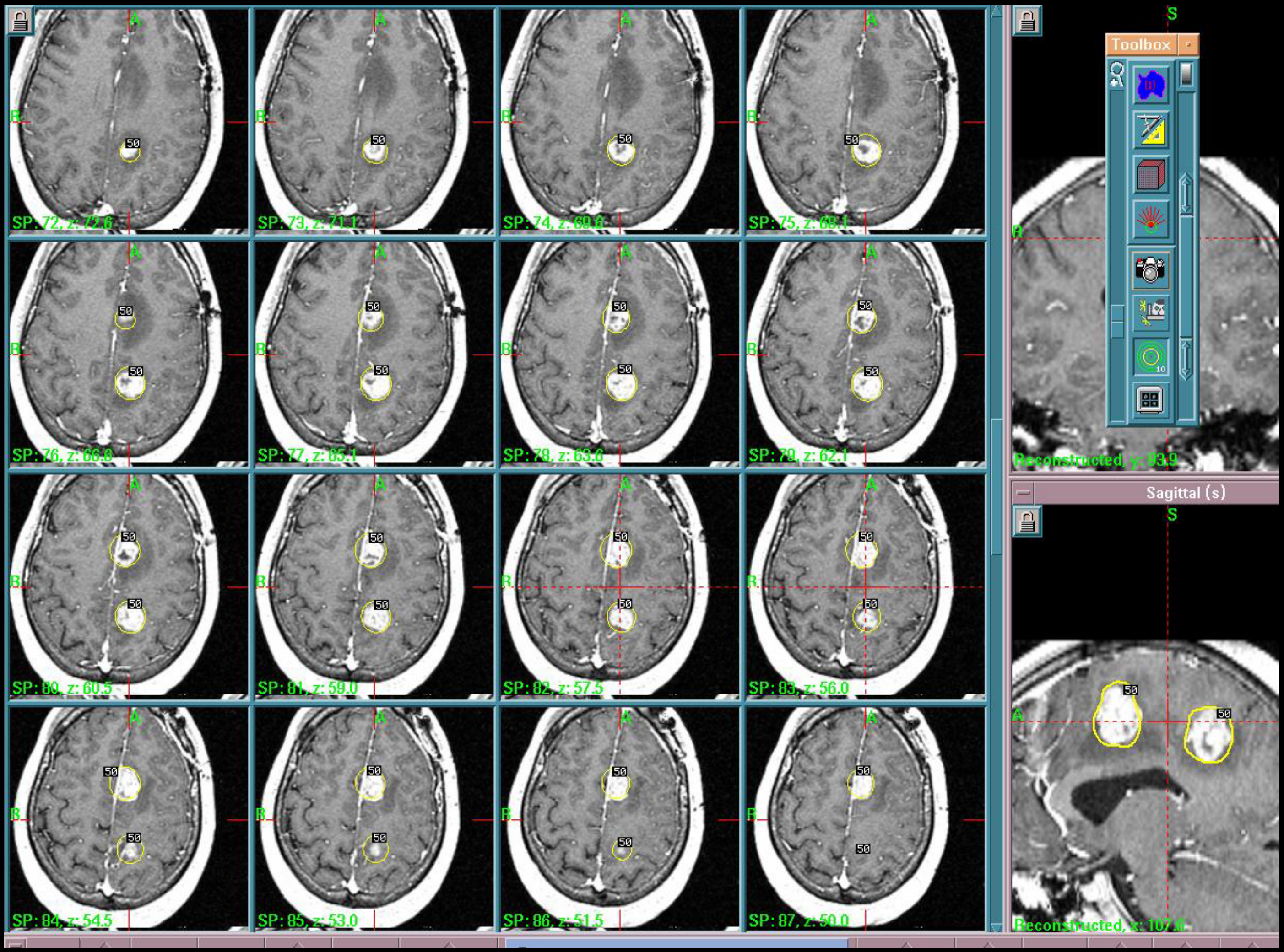


Dose plan



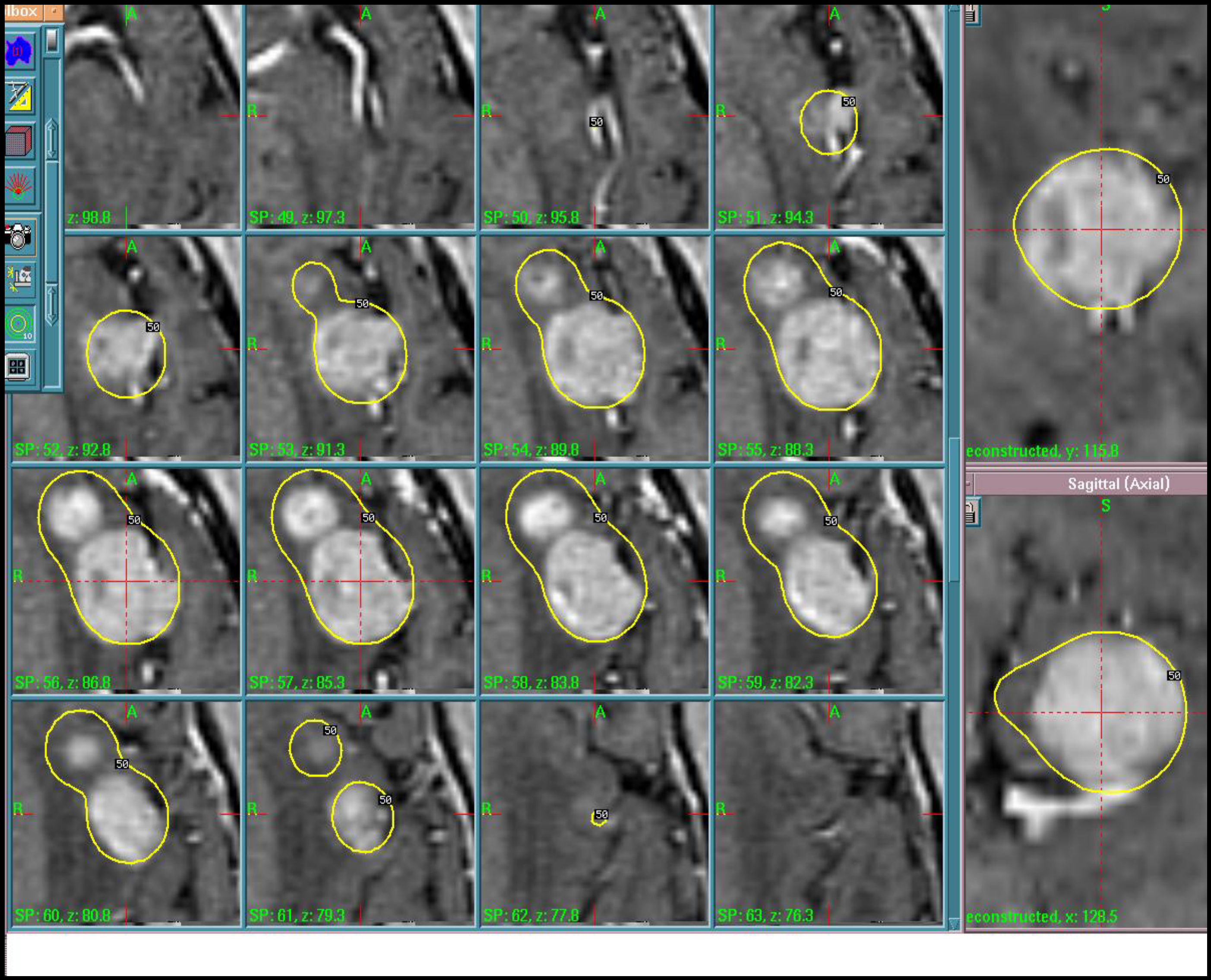
6 months post

Gamma Knife Radiosurgery



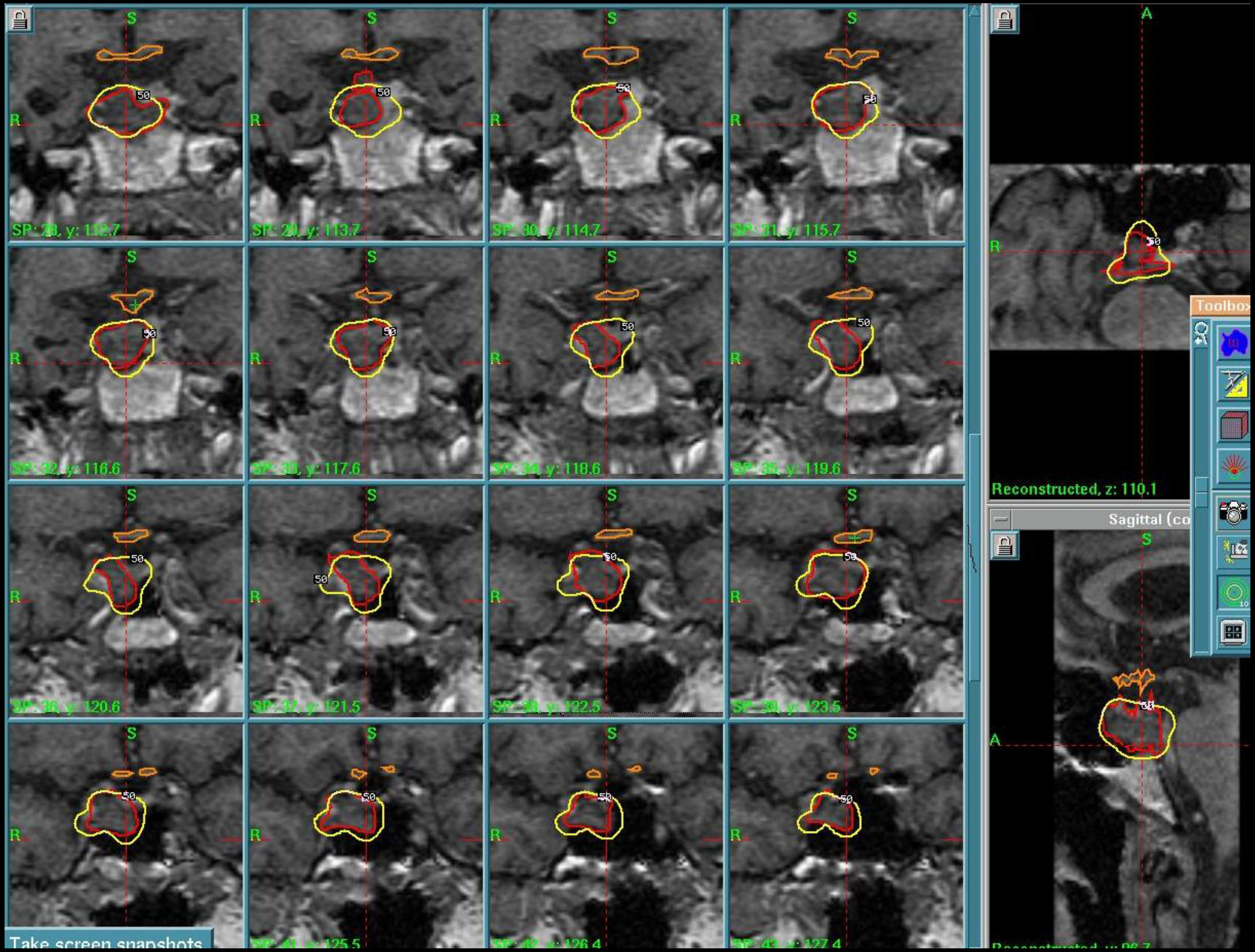
Multiple tumors in treatment planning workstation with the delivered dose in yellow.

Gamma Knife Radiosurgery



Multiple tumors in treatment planning workstation with the delivered dose in yellow.

Gamma Knife Radiosurgery



Pituitary Adenoma in red with optic chiasm in orange.