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CATHOLIC UNIVERSITY**



**SEMMELWEIS
UNIVERSITY**



Development of Complex Curricula for Molecular Bionics and Infobionics Programs within a consortial* framework**

Consortium leader

PETER PAZMANY CATHOLIC UNIVERSITY

Consortium members

SEMMELWEIS UNIVERSITY, DIALOG CAMPUS PUBLISHER

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**Molekuláris bionika és Infobionika Szakok tananyagának komplex fejlesztése konzorciumi keretben

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TÁMOP – 4.1.2-08/2/A/KMR-2009-0006



NEURAL INTERFACES AND PROSTHESES

(Neurális interfészek és protézisek)

LECTURE 4

STEREOTAXIC TECHNIQUE –NAVIGATION IN THE BRAIN

(Sztereotaxikus módszer – helymeghatározás az agyban)

GYÖRGY KARMOS

AIMS:

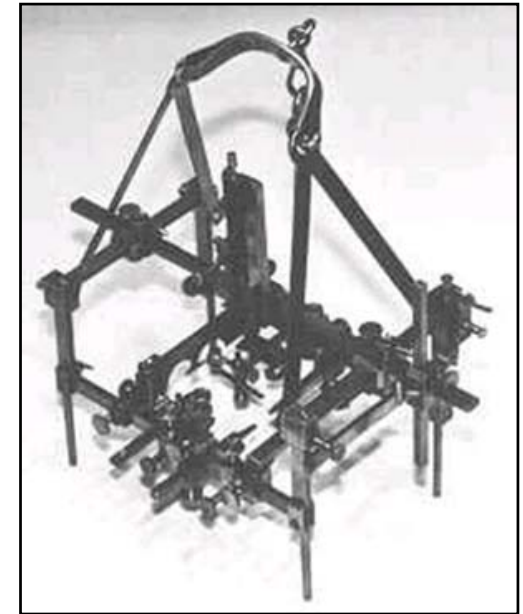
- In this lecture the students will get acquainted with the principle of the stereotaxic technique. Examples will be presented from animal research and the human application of the stereotaxic method will be discussed.
- In modern neurosurgery neuronavigation method is also used for localization structures in the brain. This technique does not need frame fixed to the head of the patient.
- Present day neurosurgery uses computer softwares for fusion of neuroimaging data in order to plan surgical approaches in the brain.

HISTORY OF ANIMAL STEREOTAXIC TECHNIQUE

By the beginning of the 20th Century neurophysiologists started the functional study of the subcortical brain structures. A method was needed to exactly localize these deep-seated nuclei.

In 1908 two English scientists, Victor A. Horsley and Robert H. Clarke invented the stereotaxic apparatus called for a long period „Horsley-Clarke apparatus”. This served for intracerebral navigation in vertebrates.

The method was further developed by S. W. Ranson in the USA in the thirties. Stereotaxic atlases were published for the different species. Nowadays most experimental manipulations in the vertebrate brains are done with the help of the stereotaxic method.



The first stereotaxic apparatus of Horsley and Clarke (1908)

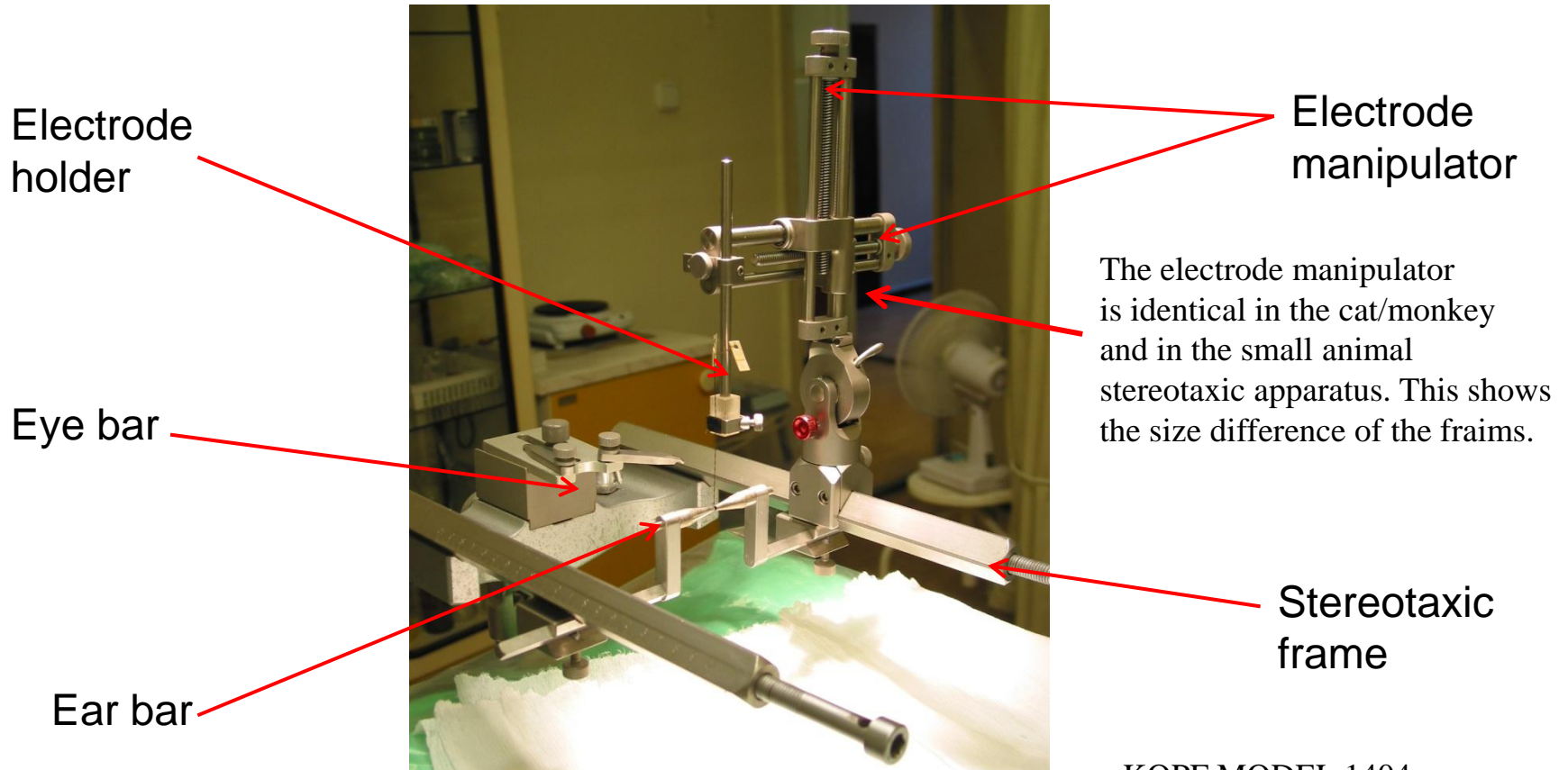
DEFINITIONS

The term *stereotaxic* comes from the Greek *stereos*: solid and *tassein*: arrange.

Stereotaxic apparatus consists of a metal frame that serves for rigid fixation of the head of the animal in reference to the coordinate system. In rodents the head is fixed by two ear bars inserted into the external auditory meati and the tooth bar over which the front teeth are placed. Reference points are also on the skull the bregma and lambda sutures. In cats two ear bars and two eye bars placed on the inferior orbital ridges are used. The frame also serves as the base for the manipulation of the positioners or electrode holders in the three dimensional coordinate system.

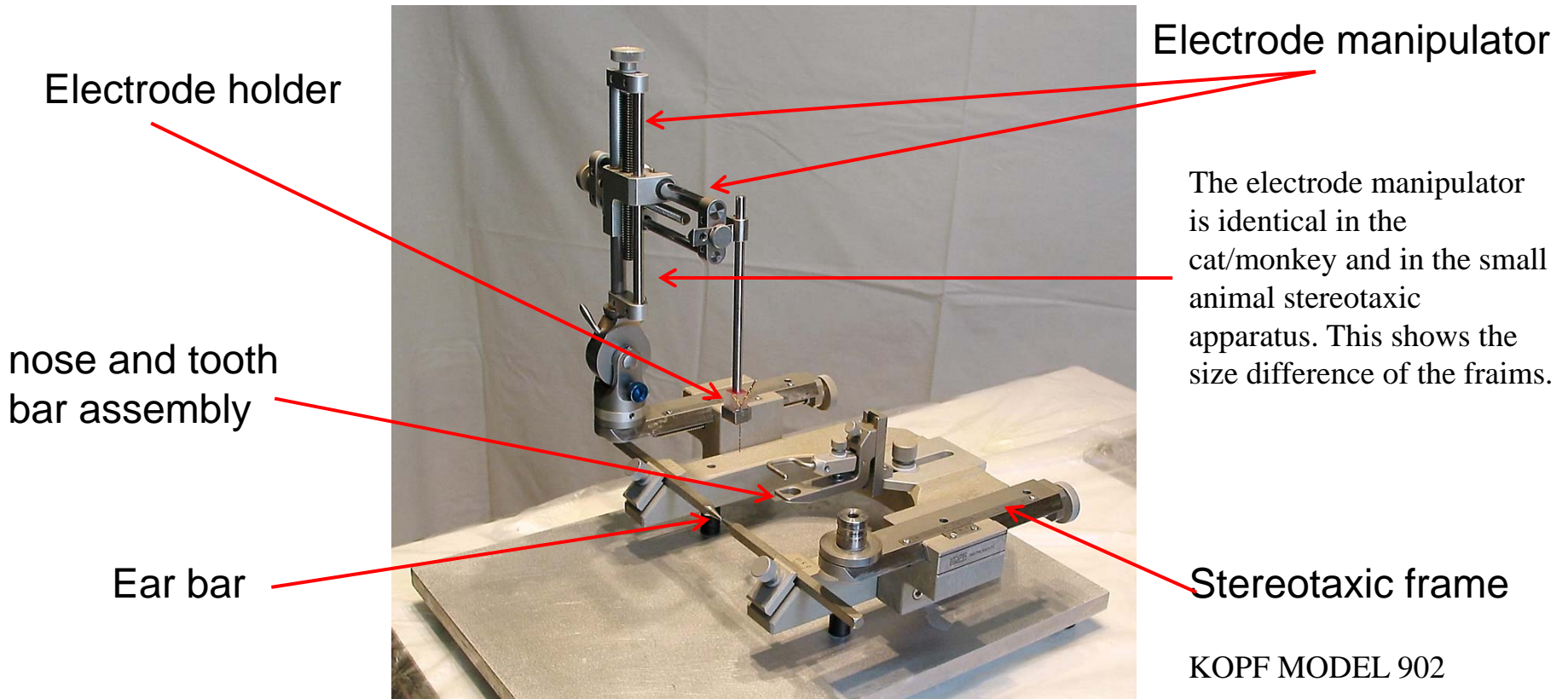
Stereotaxic atlas contains cell and fiber stained brain sections as well as schematic figures based on these sections. Sections are made in all three dimensions: front - rear direction, medial - lateral direction, dorsal - ventral direction.

- **STEREOTAXIC APPARATUS FOR CATS AND MONKEYS**



KOPF MODEL 1404

SMALL ANIMAL STEREOTAXIC INSTRUMENT



CHRONIC ELECTRODE IMPLANTATION IN RAT

Chronic electrode implantation means that the animal recovers from the operation with the implanted electrodes fixed to its skull. After recovery multiple recording or stimulation sessions can be performed with this animal.

The operation is carried out in surgical anesthesia with sterilized instruments.

The chronically implanted electrodes are usually thin enamel insulated tissue friendly stainless steel wires. Twisted wire electrodes are easy to fabricate. They are used for deep brain recording or stimulation, they cause relatively little harm to brain tissue and provide stable recordings for long time.

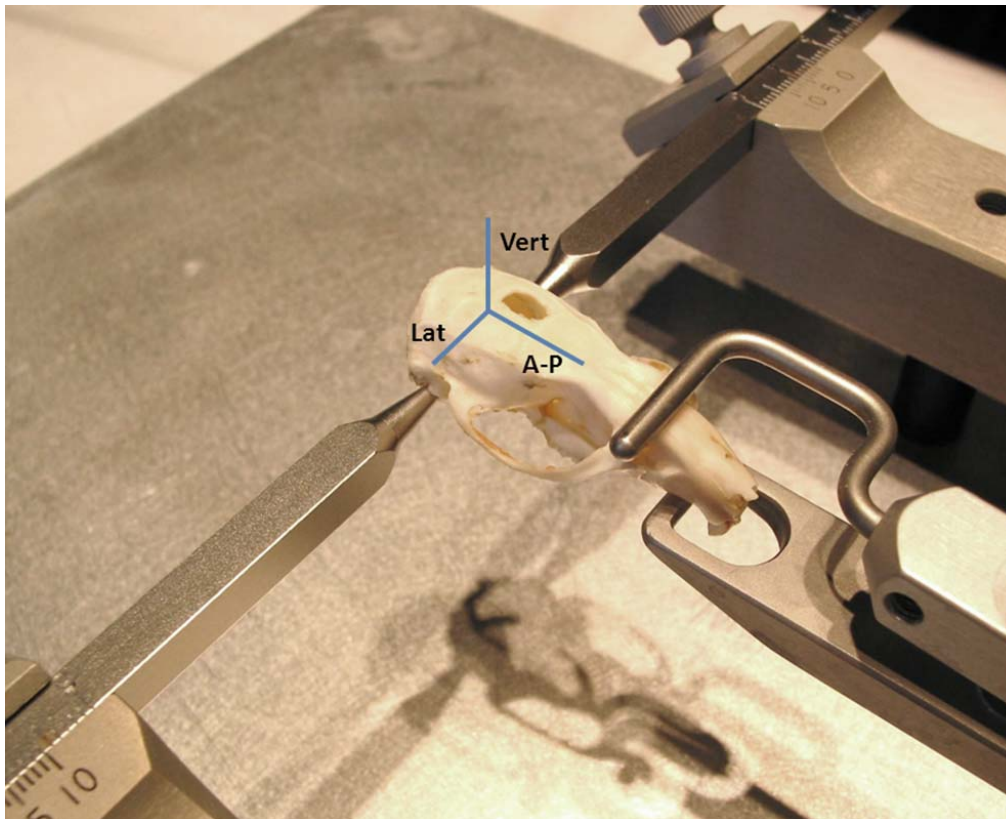
The electrodes are fixed to the skull by dental filling and acrylic materials.

For recording of brain electrical activity stainless screws are fixed into the skull as reference and ground electrodes.

The electrodes are connected to miniature multicontact socket to which the multilead cable can be connected for the time of the experiments.

Chronically implanted rat can be used in behavioral experiments for months.

RAT SKULL IN THE STEREOTAXIC FRAME



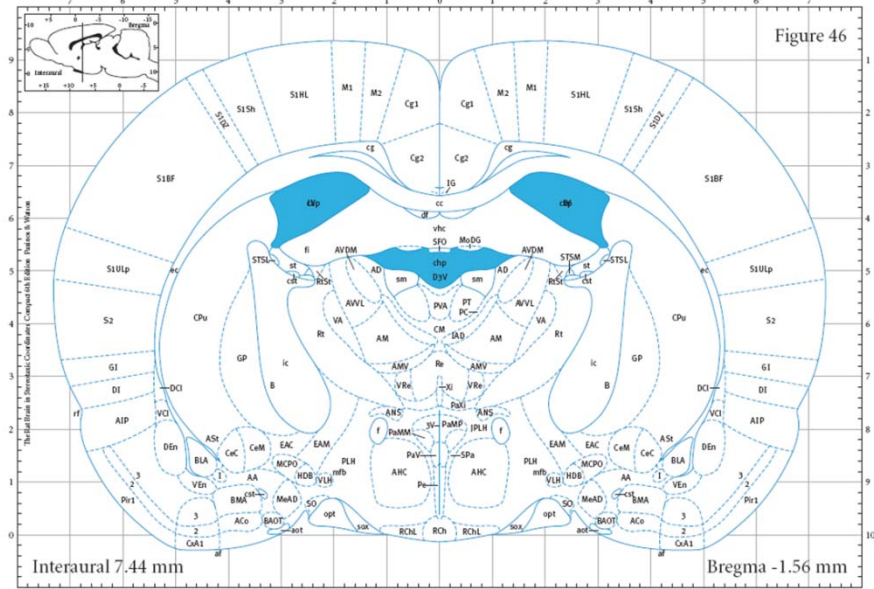
The three coordinates are indicated:

A-P.: front - rear direction

Lat.: medial - lateral direction

Vert.: dorsal - ventral direction

STEREOTAXIC COORDINATES

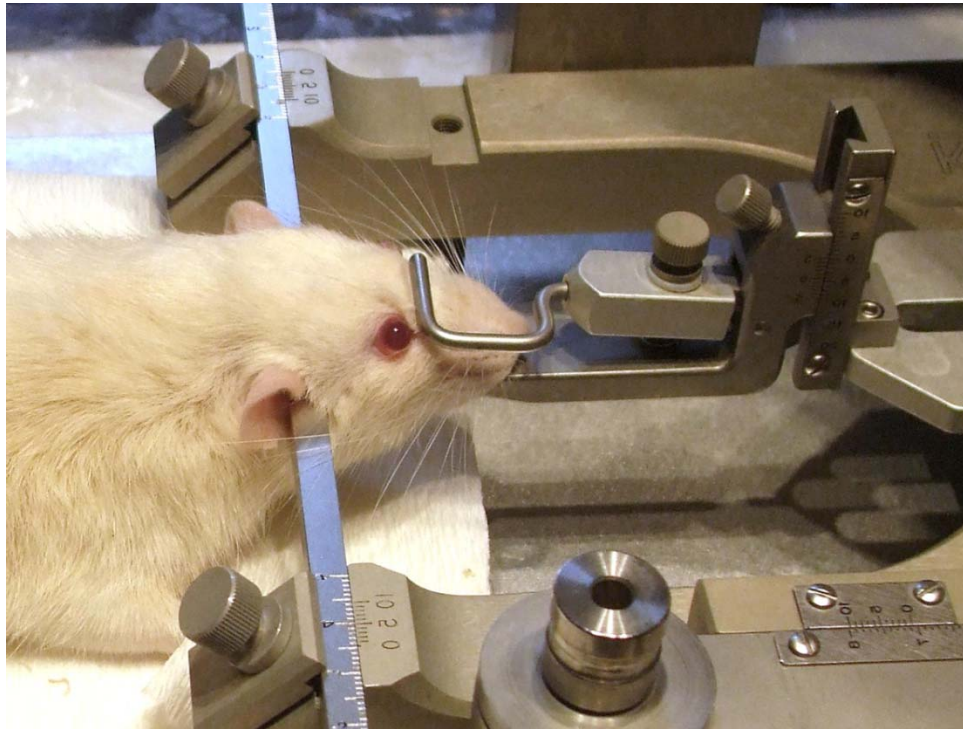


Paxinos, G., Watson, C.,
The Rat Brain in Stereotaxic Coordinates
6th ed., Academic Press, 2009.

Continued from Figure 45
 MCPD mesencephalic prosencephalic nu
 MaAD medial amygdaloid nu, ant dors
 mfb medial forebrain bundle
 MODG molecular layer dentate gyrus
 MPK medial preoptic area
 OPT optic tract
 PMM paraventricular by, med magnocellular
 PMP paraventricular by, med parvocellular
 PVV paraventricular by nu, ventral
 PVM paraventricular nu of thalamus
 PC parvocellular thalamic nu
 Pp paraventricular hypothalamic nu
 PVL parvocellular layer 1
 PLH peduncular part of lat hypoth
 PT paratenial thalamic nu
 PVA paraventricular thalamic nu, ant
 RCh retrochiasmatic area
 RChL retrochiasmatic area, lateral
 RP reticular thalamic nu
 rf rhinal fissure
 RE reticular thalamic nu
 RST reticulostriatal nu
 S1BF prin somatosens, barrel field
 S1DZ prin somatosens, dyp and
 S1L prim somatosens, hindlimb
 S1SH prim somatosens, hindlimb
 S1SHL prim somatosens, shoulder
 S1ULP prim somatosens, upper lip
 S2 secondary somatosensory cr
 SFO subfornical organ
 SM nu of the stria medullaris
 SM stria medullaris thalamus
 SO supraoptic nu
 SOH supraoptic decussation
 SPM subparaventricular zone hypothal
 st stria terminalis
 STMPM bed nu st, med, dx, posterior
 STSL bed nu st, supracap, dx, lat
 STSM bed nu st, supracap, dx, lat
 TS triangular septal nu
 VA ventral anterior thalamic nu
 VCI ventral part of claustrum
 VEN ventral endopituitary nu
 VHC ventral hippocampal coman
 VLH ventrolateral hypothalamic nu
 VRE ventral reuniens thalamic nu
 XI xiphoid thalamic nu

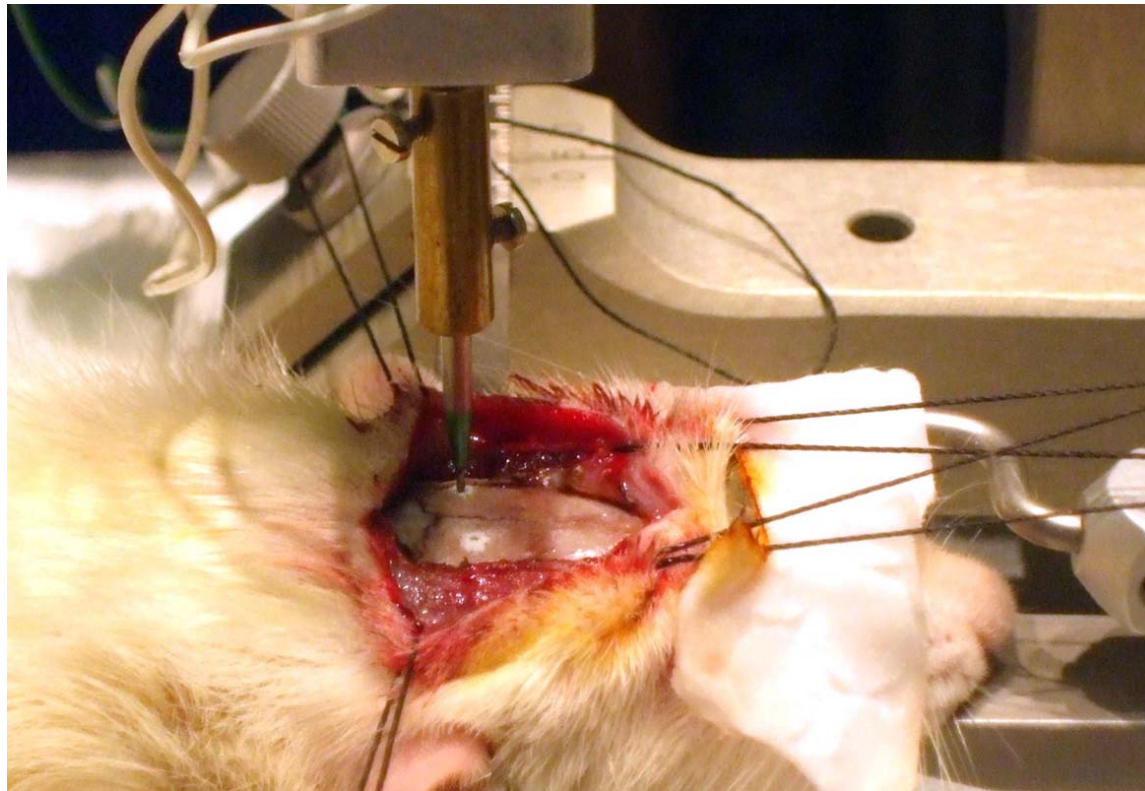
Two pages of the stereotaxic atlas. Left the histological section, right the map of the structures with the coordinates.

ANESTHETIZED RAT FIXED IN THE STEREOTAXIC FRAME



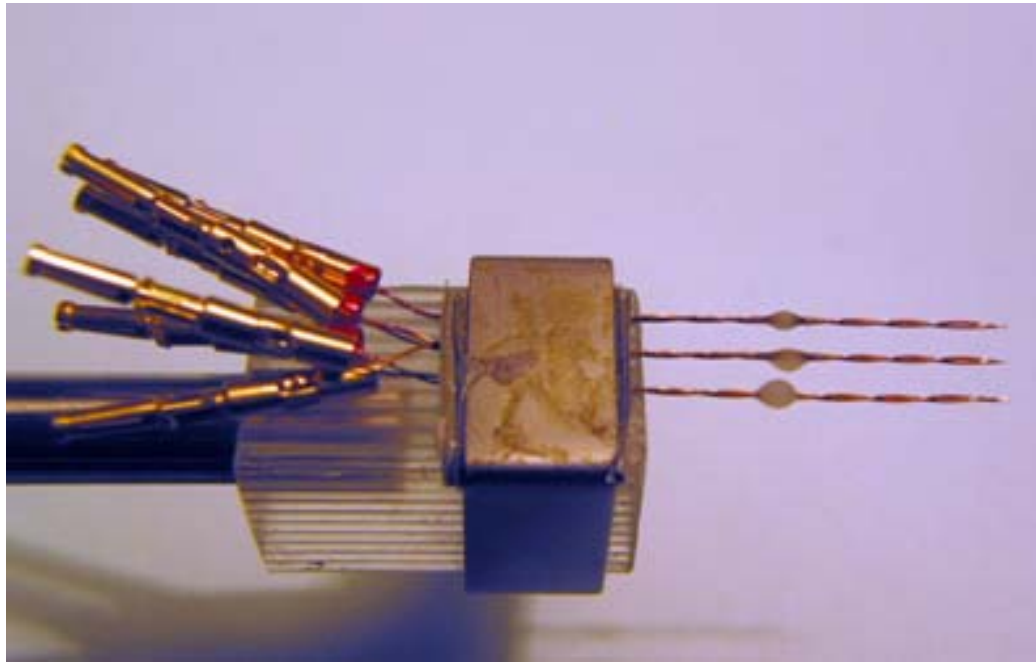
The head is fixed by the ear bars and the nose and tooth bar assembly.

STEREOTAXIC ELECTRODE IMPLANTATION 1



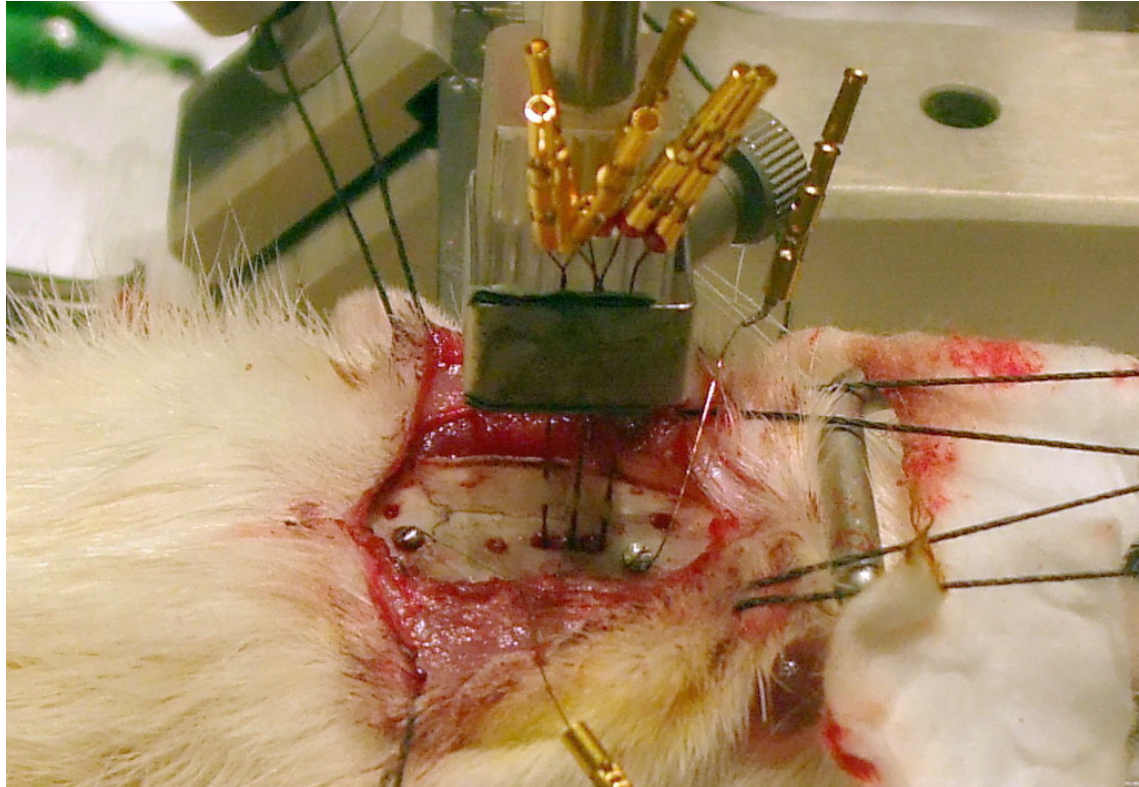
Holes in the skull are made by a drill fixed in the stereotaxic manipulator.

STEREOTAXIC ELECTRODE IMPLANTATION 2



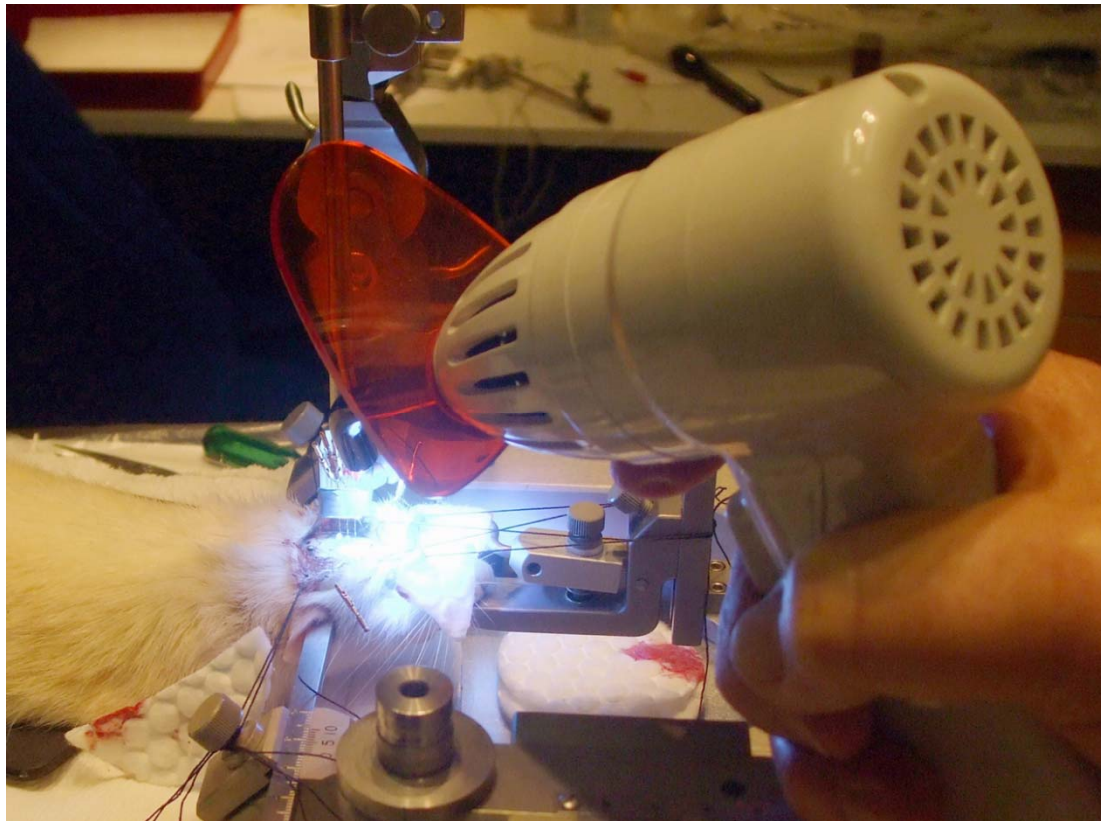
Three pairs of twisted wire electrodes are fixed in the electrode holder. The enamel insulation is removed from the tip of the wires (right). At the other end of the wires female connectors are crimped (left). Drops of adhesive are used to fix the twisted wires.

STEREOTAXIC ELECTRODE IMPLANTATION 3



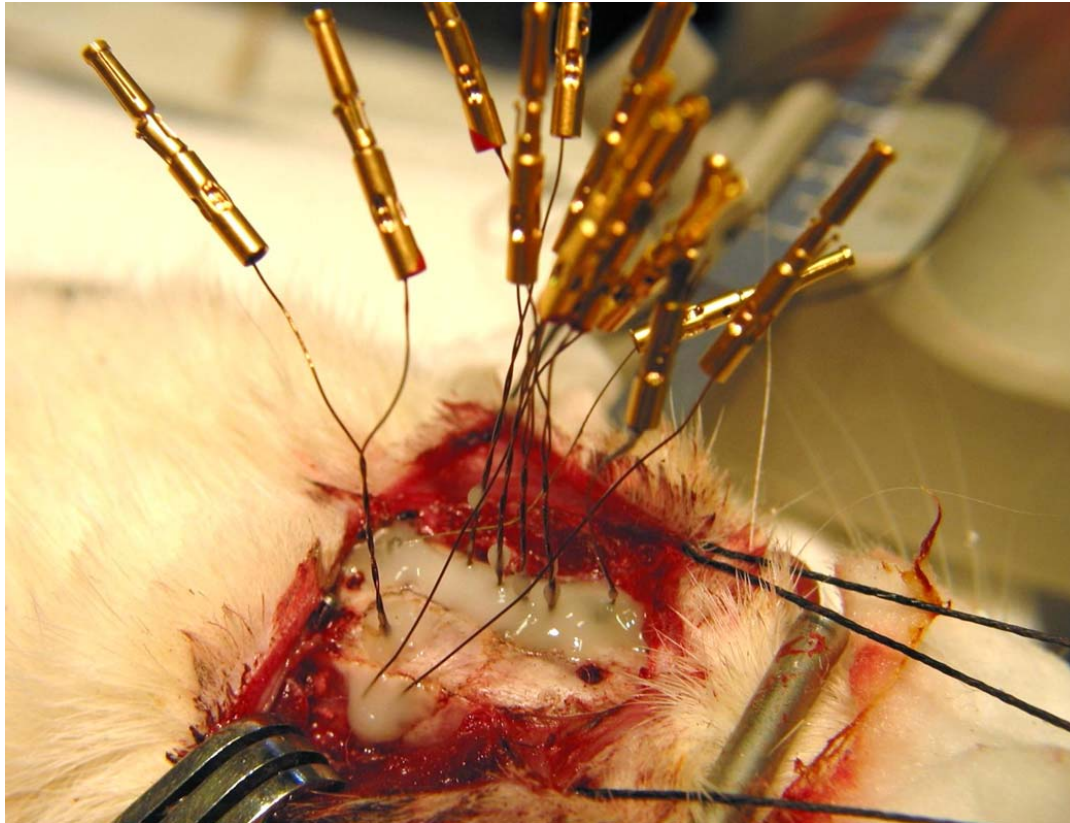
Three pairs of electrodes are inserted into the brain according to the stereotaxic coordinates.

STEREOTAXIC ELECTRODE IMPLANTATION 4



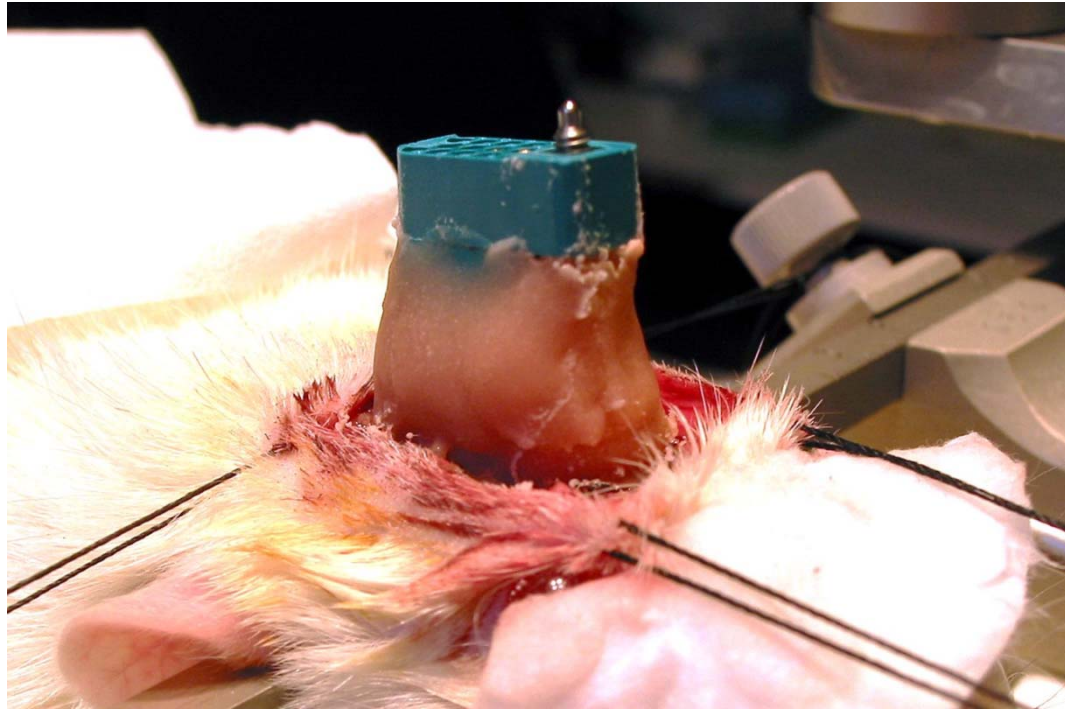
The electrodes are fixed to the skull by light curing dental adhesive.

STEREOTAXIC ELECTRODE IMPLANTATION 5



Seven pairs of electrodes are implanted and fixed to the skull.

STEREOTAXIC ELECTRODE IMPLANTATION 6



The miniature connectors were inserted into the body of the connector and the whole implant is fixed to the skull by dental acrylic. Finally the wound is closed by sutures.

STEREOTAXIC ELECTRODE IMPLANTATION 7



Next day after the implantation the rat is well and ready for the behavioral experiments.

THE BEGINNING OF MODERN NEUROSURGERY



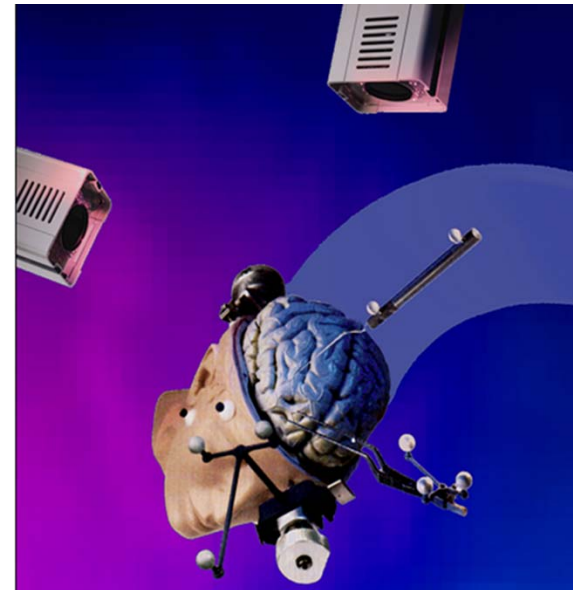
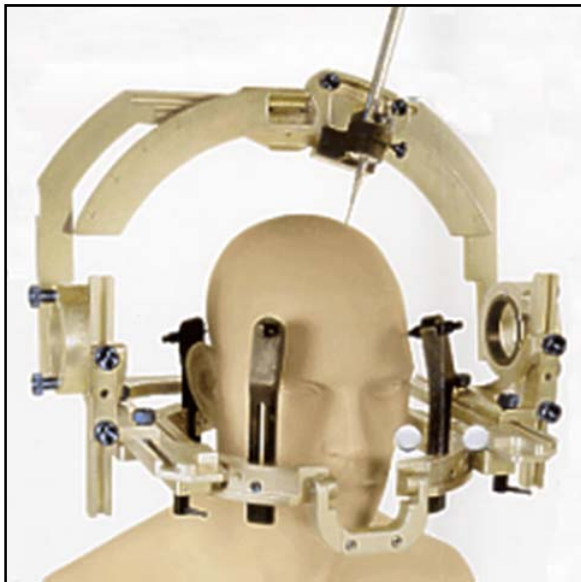
Harvey Cushing (1869-1939)



NEURONAVIGATION

Minimal invasive neurosurgery is becoming more and more standard in neurosurgical procedures. Neuronavigation is important technique in this.

Stereotactic neurosurgery represent the „**frame based**” neuronavigation. The other method is the „**frameless**” neuronavigation. Both methods are based on brain imaging like MR, CT and PET.



STEREOTAXIC TECHNIQUE IN HUMANS

Modern neurosurgery dates back to the period of Harvey Cushing (1869-1939).

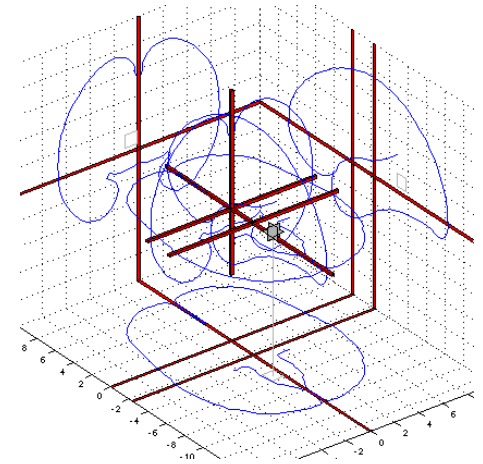
Stereotaxic method (or as is written in most neurosurgical text *stereotactic method*) was rarely used since the Horsley -Clarke apparatus could not be adapted for humans because there were no good reference points. Only modern imaging techniques solved this problem.

The up to date human stereotactic method was developed by American (Ernest A. Spiegel and Henry T. Wycis, 1947) and Swedish (Lars Leksell, 1949) neurosurgeons. They used intracerebral reference points, Spiegel and Wycis used traditional Cartesian coordinates while Leksell introduced the polar coordinate system that easier can be calibrated in the operating room.

Human application of stereotactic technique opened the door for the development of functional neurosurgery and nowadays many thousands suffering Parkinson's disease and other movement disorders are helped by minimal invasive neurosurgical interventions.

TALAIRACH COORDINATES

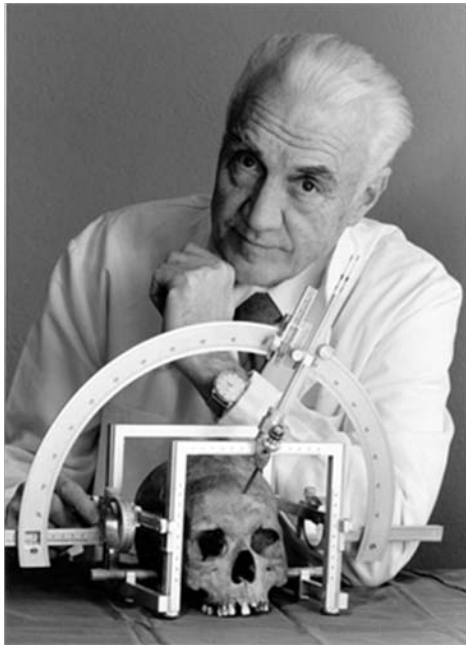
Jean Talairach (1911-2007) French neurosurgeon developed the human brain coordinate system, named after him. It uses intracerebral reference points. They are the horizontal line connecting the anterior and posterior commissures serving a vertical zero. The midsagittal plane through these points serves the vertical coordinate. The rostral- caudal coordinates are measured from the anterior commissure. The limitation of this atlas is that there are large size differences in the human brains.



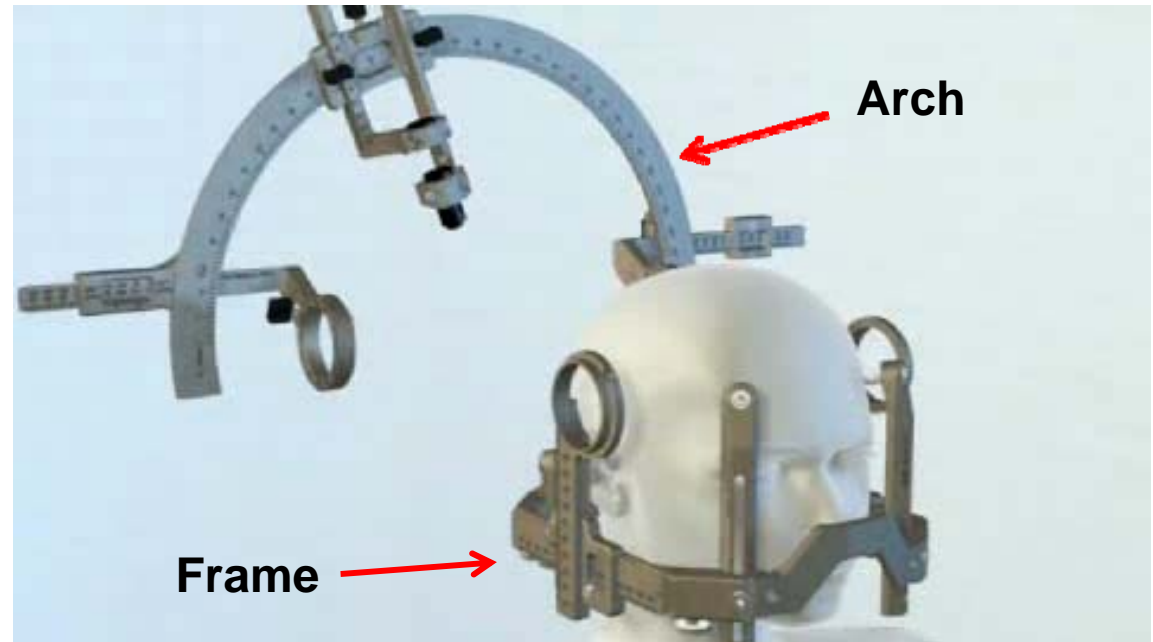
Talairach coordinates

Today using Magnetic Resonance Imaging (MRI) and Positron Emission Tomography (PET) stereotactic parameters can be exactly defined in each individual patient. Still the data can be adapted to the atlas data that makes the surgical planning easier.

LEKSELL STEREOTACTIC SYSTEM®



Lars Leksell 1907-1986



The Leksell Stereotactic System was developed by Lars Leksell, the professor of the Karolinska Institute. The basic components of the Leksell Stereotactic System are the Coordinate Frame and the Multi Purpose Stereotactic Arc.

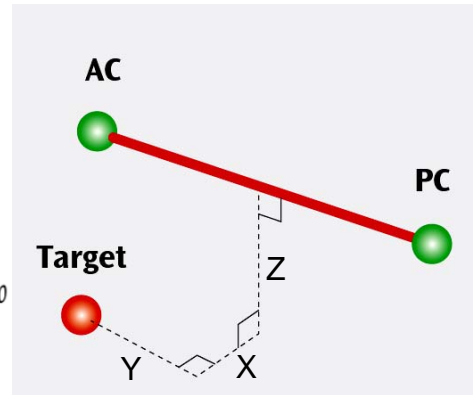
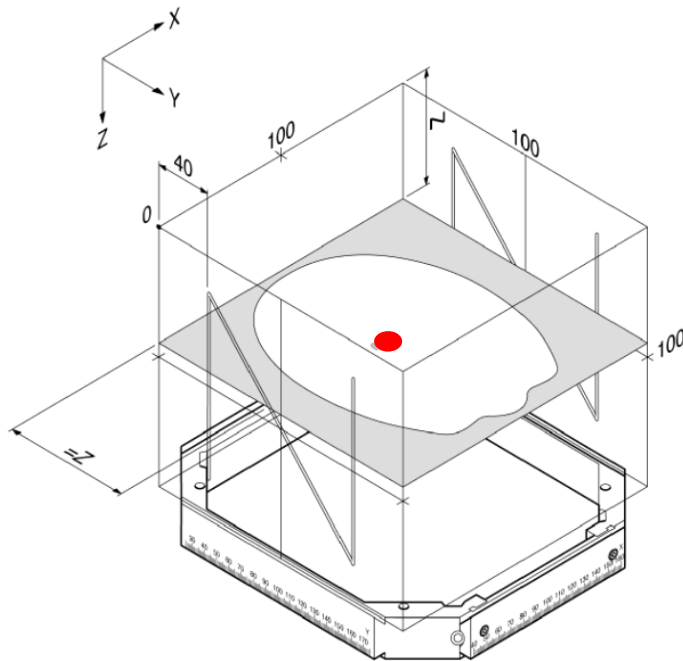
www.electa.com

LEKSELL STEREOTACTIC SYSTEM®

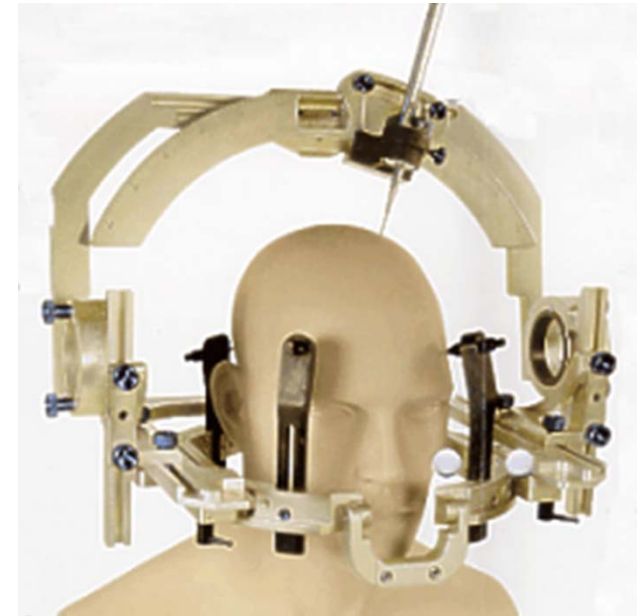


The Frame is fixed to the patients head with four screws in local anesthesia. MRI, CT or Angio can be made while the frame is attached. The indicator box generates positional marks during scanning. www.electa.com

LEKSELL STEREOTACTIC SYSTEM®



AC: anterior commissure
PC: posterior commissure



The Frame serves as the base of the coordinate system. The target point can be determined in relation to the AC- PC line.

The positioner attached to the Arch can reach any structure in the cerebrum. www.electa.com

LEKSELL STEREOTACTIC SYSTEM®



The flexibility of the System makes possible the approach from different directions.

LEKSELL STEREOTACTIC SYSTEM®



Brain biopsy



Elekta Endoscope Adapter serves for biopsy,
Leksell MicroDrive for positioning
recording and stimulating electrodes.



Leksell MicroDrive

www.elekta.com

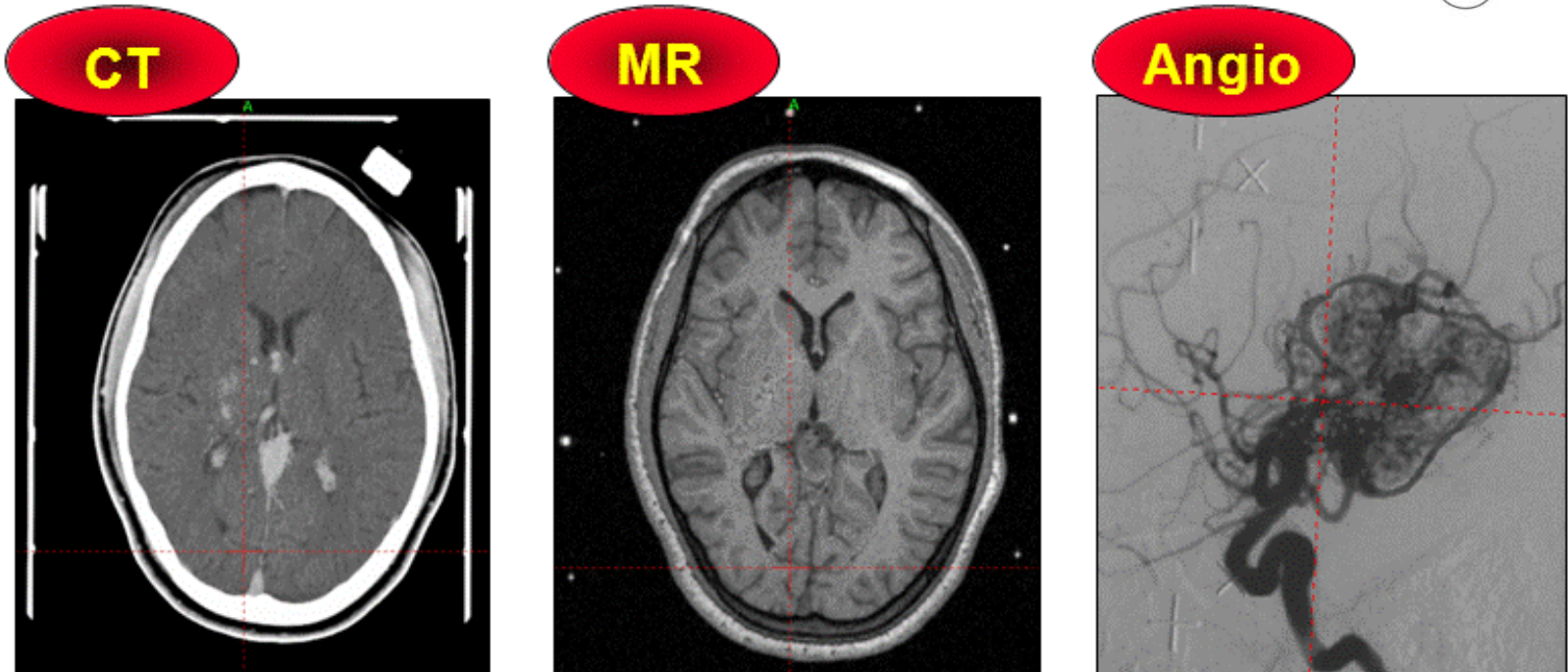
Leksell SurgiPlan[®]



Leksell SurgiPlan[®] is an advanced image-based neurosurgical planning software, specifically designed for Leksell Stereotactic System[®]. The Linux operating system based modular platform combines advanced image handling options with a new graphic interface for excellent ease-of-use.

www.electa.com

Leksell SurgiPlan®

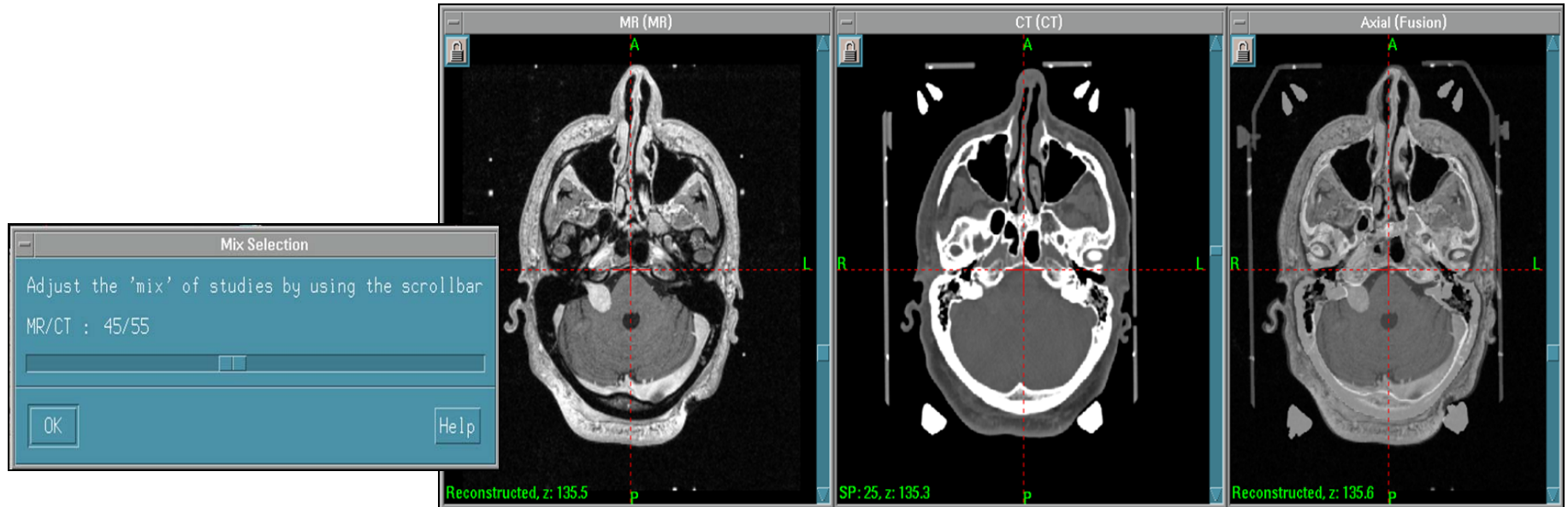


Pre-operative planning can be made through co-registration of frame-based and frameless image studies from CT and MR scanners. Leksell SurgiPlan software can import CT, MR and angiographic images. Once images are imported, they are automatically scaled.

www.electa.com



Leksell SurgiPlan®



Interactive image fusion of CT and MR images.

The fused images have the same high accuracy as the original images, since both image studies are defined in Leksell stereotactic space by Leksell Coordinate Frame.

Leksell SurgiPlan®

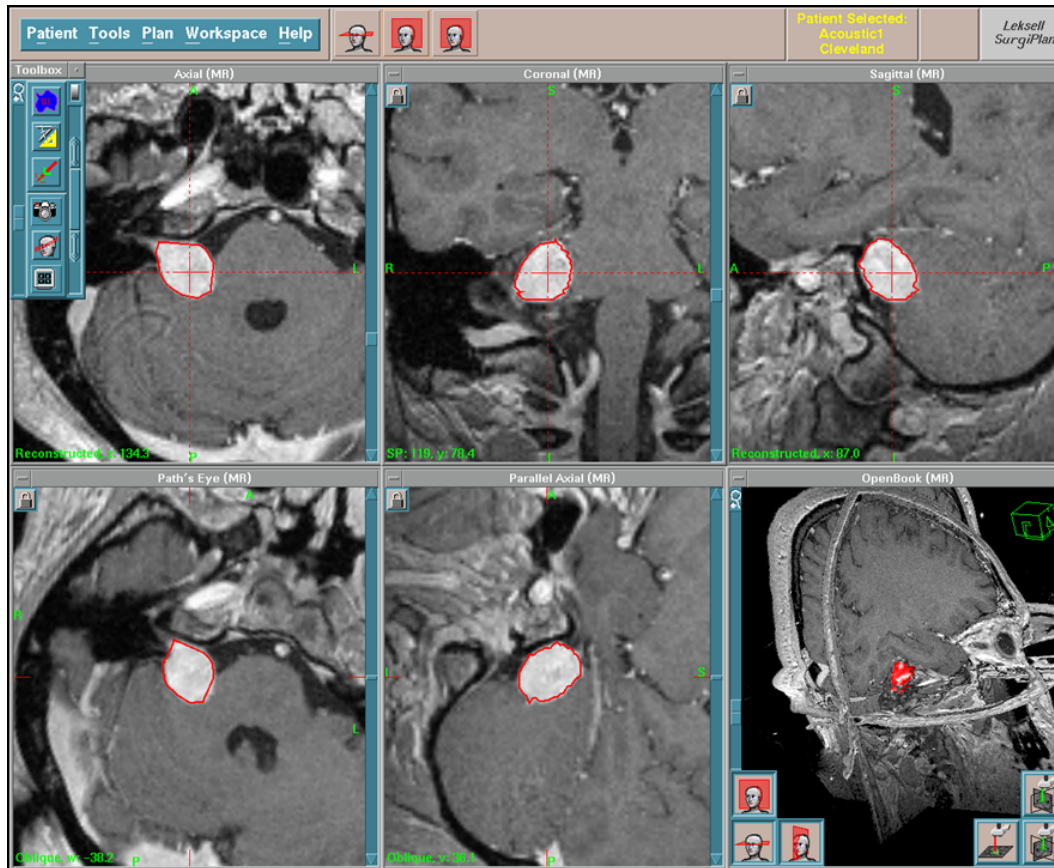


Targets can be easily defined with the semi-automatic outline function, which also allows for complex non-continuous regions.



www.electa.com

Leksell SurgiPlan®

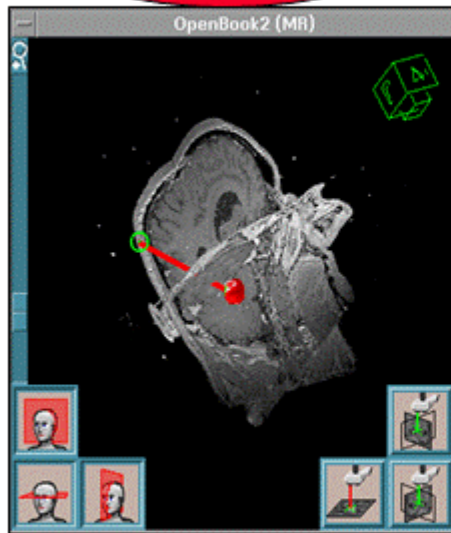


Cross-hair position correlates all open views and different imaging modalities. Real time image reformatting, continuous zoom and gray scale mapping gives immediate visual feedback for fast and accurate planning.

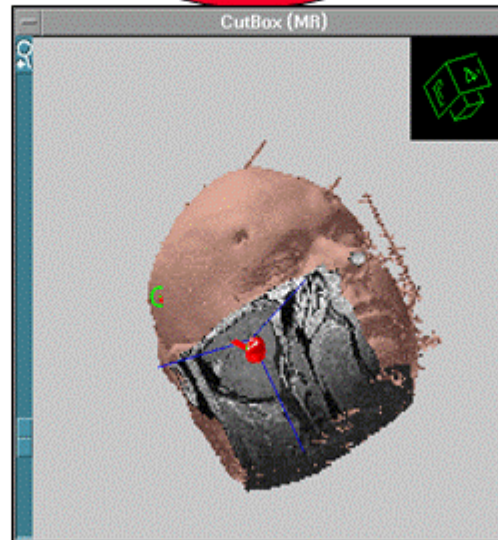
Leksell SurgiPlan®



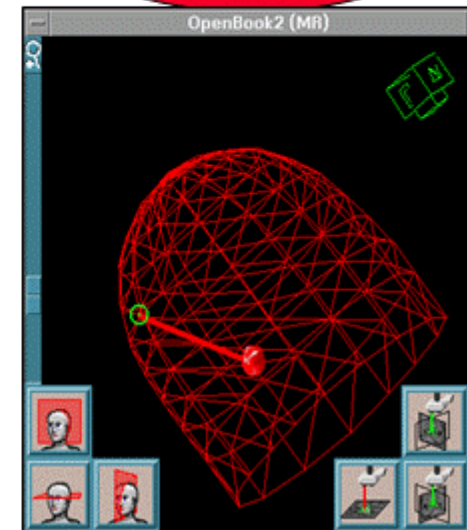
Open Book



Cut Box



Wire Frame

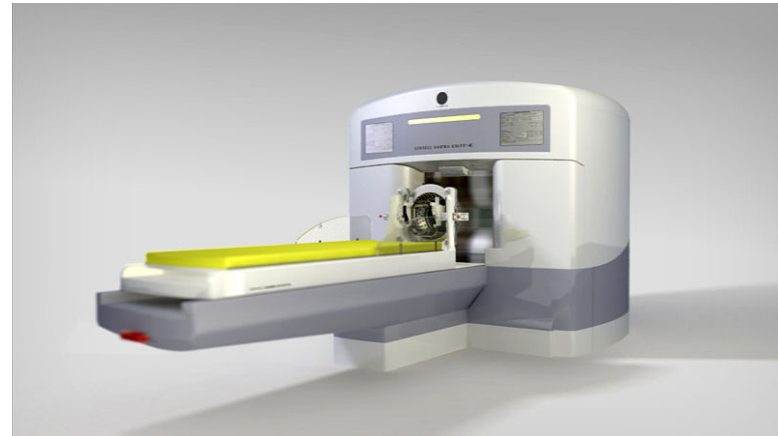
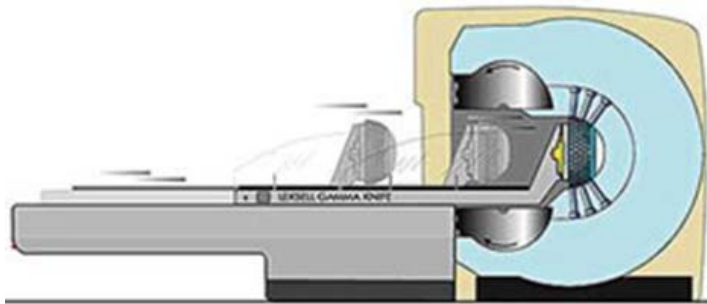


It offers powerful functions to visualize and analyze patient images displayed in different 3-D renderings, facilitating more complete planning validation.

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NEUROSURGICAL APPLICATION OF STEREOTACTIC TECHNIQUE

Leksell Gamma Knife®



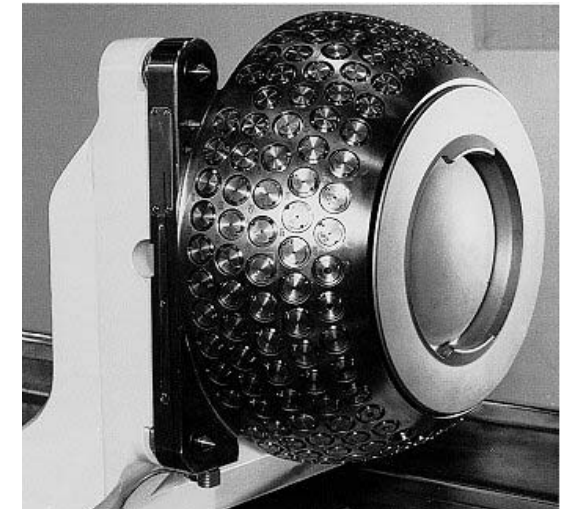
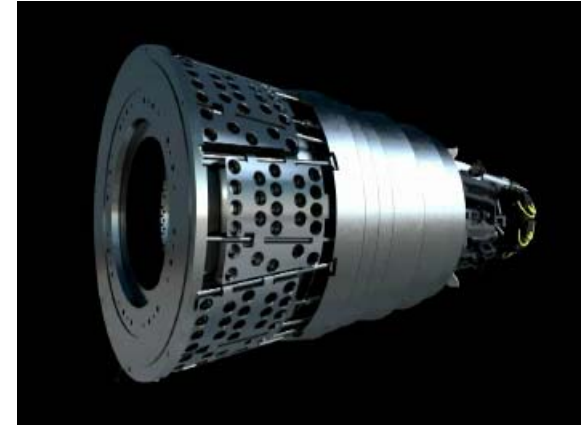
- In 1968 Lars Leksell introduced gamma knife surgery.
- In 1986 first commercially dedicated Leksell Gamma Knife was introduced.

The principle of gamma surgery is that high intensity gamma radiation kills cancer cells and shrinks tumors. The aim is to focus a series of low intensity gamma radiation beams to one single point in the brain where the tumor or malformation is. This is done by the Gamma knife.

LEKSELL GAMMA KNIFE®

Gamma Knife typically contains 201 cobalt-60 sources of approximately 30 curies (1.1 TBq), each placed in a circular array in a heavily shielded assembly. The radiation beams converge with high accuracy on the target. Each individual beam has low intensity and therefore does not affect the tissue through which it passes on its way to the target. The beams converge in an isocenter where the cumulative radiation intensity becomes extremely high.

The extreme precision of Leksell Gamma Knife, better than 0.5 mm, makes it possible to administer a high radiation dose to the lesion with minimal risk of damaging healthy tissue.



GAMMA KNIFE SURGERY

The first step of Leksell Gamma Knife surgery is to precisely pinpoint the tumor or other problem by the special stereotactic head frame.

Head frame in place MRI and CT scans are made to precisely locate the size, shape and location of the tumor, lesion or abnormality.

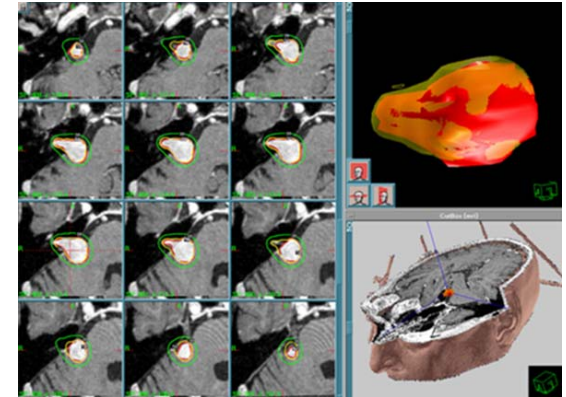
On the basis of the images using *Leksell GammaPlan*® 3-D planning software, a treatment protocol is planned.

Once the protocol is complete, the next step is the treatment. With the head frame attached to the helmet the radiation is done.

With very few exceptions, Gamma Knife surgery is given on a single occasion and without general anesthesia.

During the procedure the patient can communicate with the Gamma Knife team through a video and audio connection.

A treatment lasts from two to forty-five minutes.



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GAMMA KNIFE SURGERY



ELEKTA

www.electa.com

Gamma knife surgery is a bloodless surgery for neurological diseases. The surgery does not require the skull to be opened for performance of the operation.

Gamma knife surgery is effective for patients with benign or malignant brain tumors, vascular malformations such as an arteriovenous malformation (AVM).

Several published studies demonstrate savings of more than 50% of direct costs associated with microsurgery.

More than 500000 patients were treated by Leksell gamma knife until December 2009.



FRAMELESS NEURONAVIGATION

Frameless neuronavigation systems enable the surgeons to visualize the anatomy of a patient's brain during surgery and precisely track the location of their surgical instruments in relation to the brain anatomy.

Different techniques are used for neuronavigation and instrumental tracking: Ultrasound impulses, or infrared LED flashes reflected from specially coated spherical markers are detected. PC based systems generate location of the patient's head position and the moment to moment position of the instrument. These are integrated with the various imagin data.



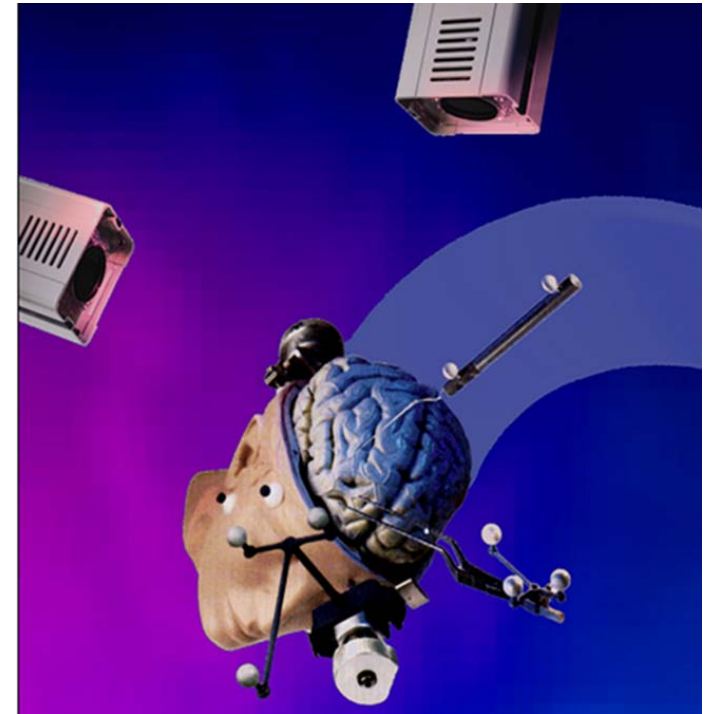
www.medtronic.com

FRAMELESS NEURONAVIGATION

Triangle marker array is fixed to the patient's head holder in a rigid position. On the operating instruments similar fiducial reference systems are located. This way both the head and the instrument data are available in the computer.

Complex mathematical algorithms via robust computer technologies made possible the real-time quantitative spatial fusion of images of the patient's brain with the created "fiducial coordinate system". The pre-surgery information integrated to the patient's real anatomy and converted into 3D images.

The technique provides surgeons with a way to navigate through the brain using the 3D images.

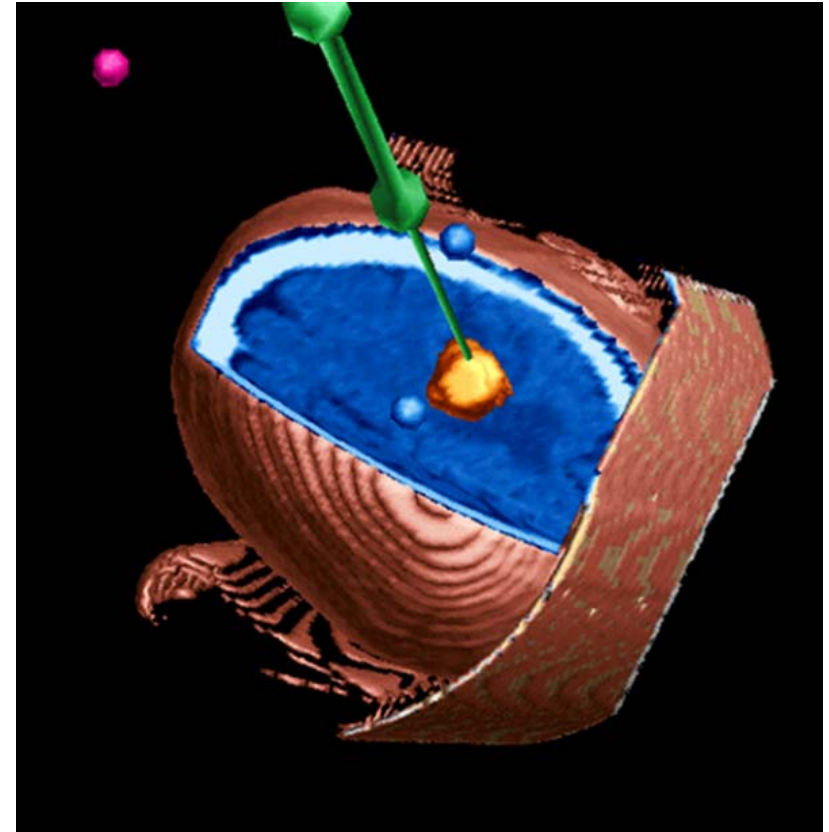


FRAMELESS NEURONAVIGATION

Application areas of frameless
neuronavigation techniques:

- tumor biopsies
- visualization of critical brain structures
- tumor resection

Image-guided surgery has revolutionized traditional surgical techniques by providing a precise treatment guidance system that can help ensure the safety of vital structures, while providing the best outcome for patients.



STEALTHSTATION S7 SURGICAL NAVIGATION SYSTEM

One of the example of the frameless neuronavigation instruments is the StealthStation® S7®, Medtronic's seventh generation surgical navigation system. Surgeons can choose between Medtronic's advanced optical surgical navigation camera, or the AxiEM™ tracking system.

AxiEM™ surgical navigation system, is electromagnetic (EM) tracking technology developed by Medtronic Navigation. It is the industry's first clinically available EM tracking solution to use unique single-coil engineering. It works by generating an electromagnetic field around the patient's target anatomy that can be tracked to triangulate the positioning of instruments and patient-tracking devices during surgical navigation.



www.medtronic.com

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http://www.waparkinsons.org/edu_research/articles/Stereotactic_Surgery.html

<http://www.bookrags.com/tandf/stereotaxic-surgery-tf/#p200045188830756003>

<http://www.med-ars.it/galleries/neurology>

REVIEW QUESTIONS:

- What are the stereotaxic reference points in rat?
- What are the stereotactic reference points in human?
- Who were the founders of the human stereotactic surgery?
- What does interactive image fusion means?
- How the gamma knife surgery is done?
- How does frameless neuronavigation works?
- What are the application areas of the neuronavigation?