

Stereotactic principles, stereotactic radiosurgery, & functional neurosurgery



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Outline

- ⚡ Definitions
- ⚡ Principles of stereotaxy: history, frames, imaging, brain atlases
- ⚡ Functional neurosurgery principles
- ⚡ “Frameless” image-guided neurosurgery
- ⚡ Psychosurgery
- ⚡ Principles of stereotactic radiosurgery

Outline

Definitions:

- ⚡ Stereotactic: from Greek meaning “to touch” in “3 dimensions” (termed by the WSSFN at Tokyo meeting in 1973)
- ⚡ Stereotaxic: from Greek meaning “3-d arrangement”, original term (coined by Horsley and Clarke) for animal surgery
- ⚡ Stereotaxis: applies to both human and animal techniques

Outline

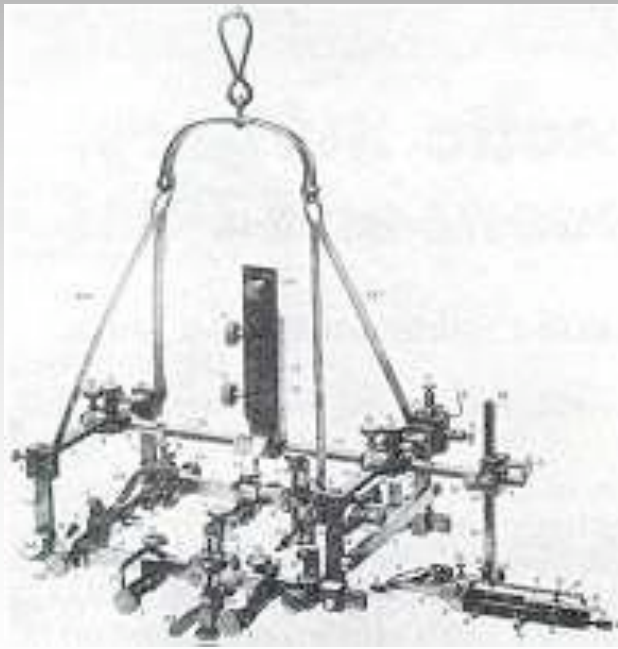
Principles of stereotaxy

- ⚡ History
- ⚡ Frames
- ⚡ Imaging
- ⚡ Brain atlases

Principles of stereotaxy: History

1873: Zurzov in Russia encephalometer

1906: Horsley & Clarke, 1st primate stereotactic device
(Structure and functions of the cerebellum examined by a new method.
Brain 31:45-124, 1908)

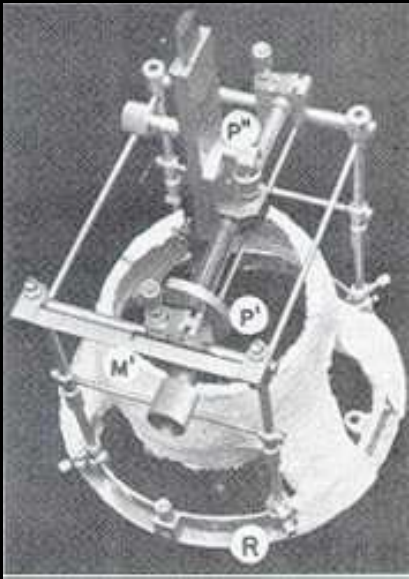


1918: Aubrey Mussen, a
physiologist at MNI built 1st
human Stereotactic frame

1920s: Dandy developed
ventriculography

1931: Moniz developed
angiography

Principles of stereotaxy: History



1946: Spiegel & Wycis built the 1st human stereoencephalotome (Science 106: 349-50, 1947)

1949: Narabayashi built stereotactic frame in Japan

1949: Leksell built his own system in Sweden, 1st arc-centre frame





1949: Talairach built his own system in France

Many others followed including Riechert (Germany), Guiot (France), Gillingham (UK)



Principles of stereotaxy: Types of frames



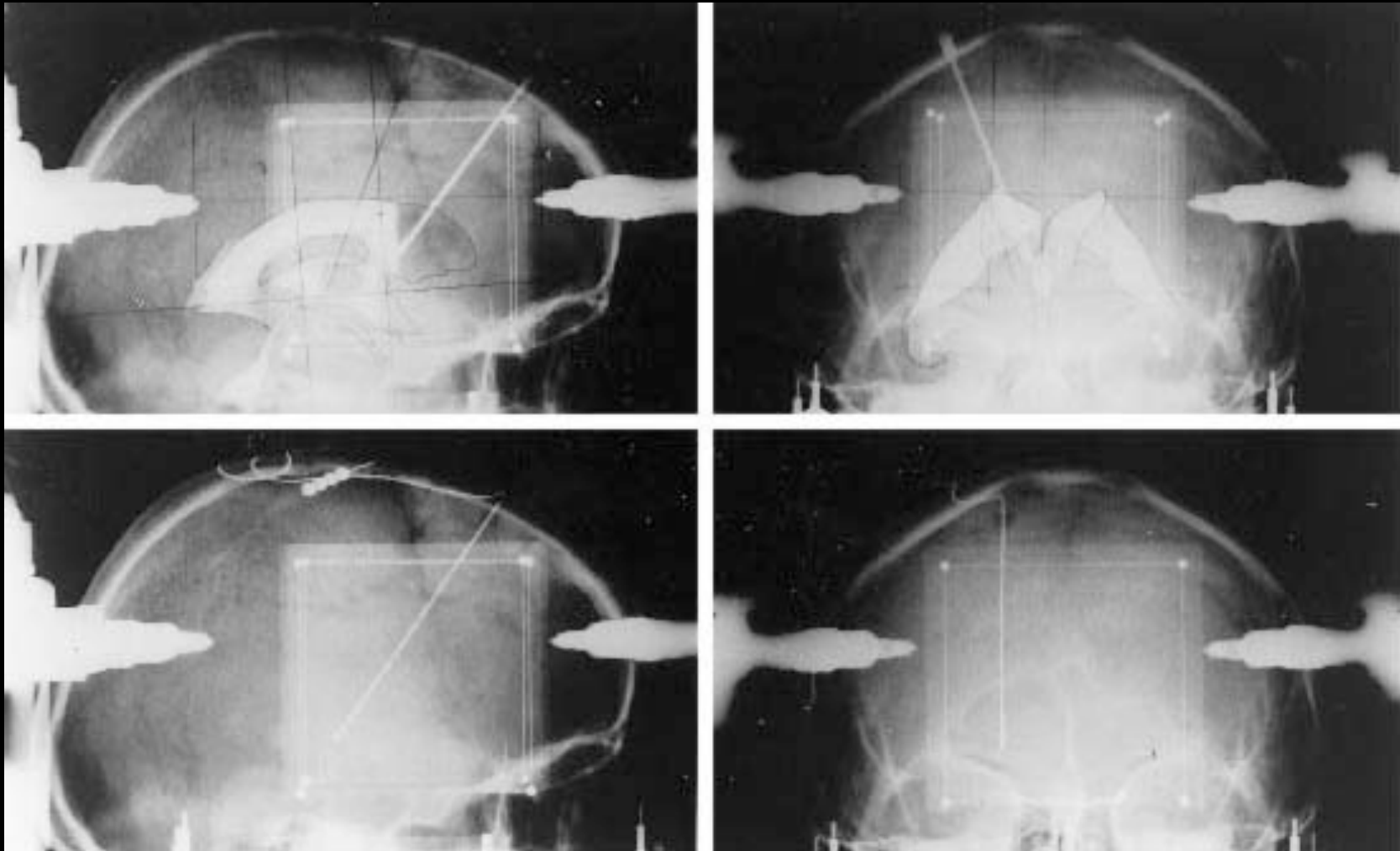
-  Orthogonal-translational
-  Arc-centred system
-  Burr-hole mounted
-  Interlocking arcs requiring phantom check

Principles of stereotaxy: Modern frames

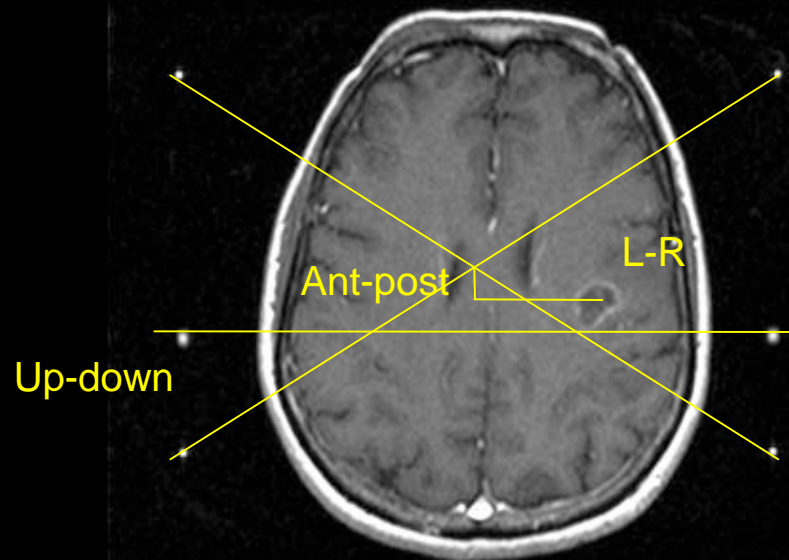


- ⚡ Radionics: CRW frame
- ⚡ Elekta: Leksell stereotactic G-frame
- ⚡ Re-locatable frames: Laitinen

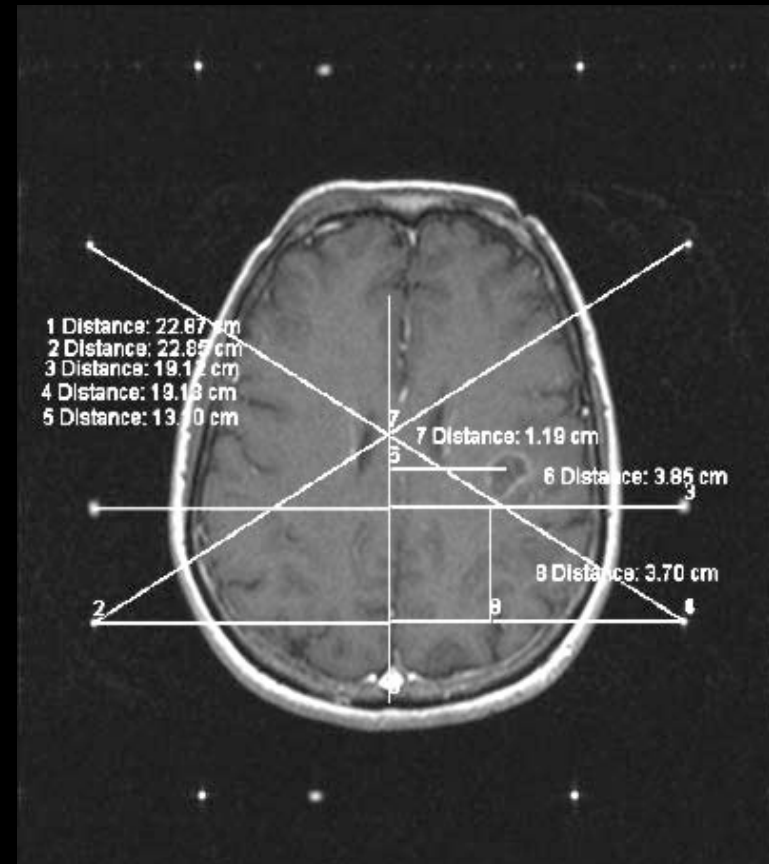
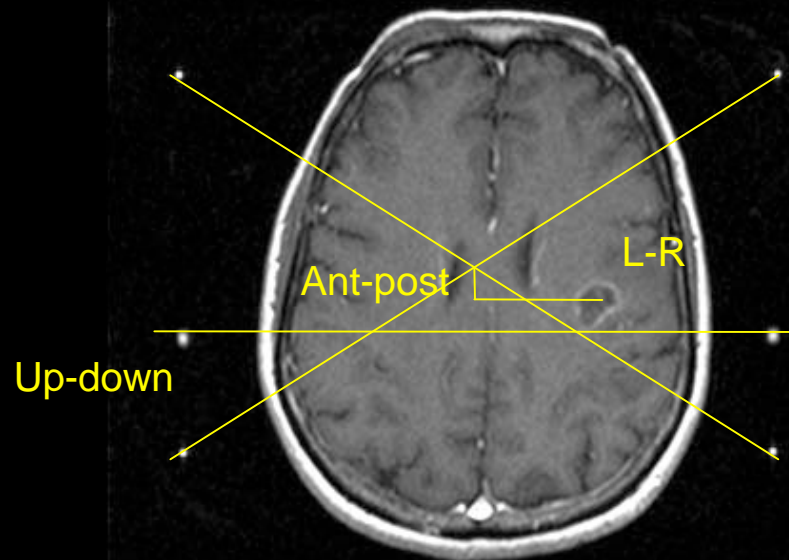
Principles of stereotaxy: Imaging



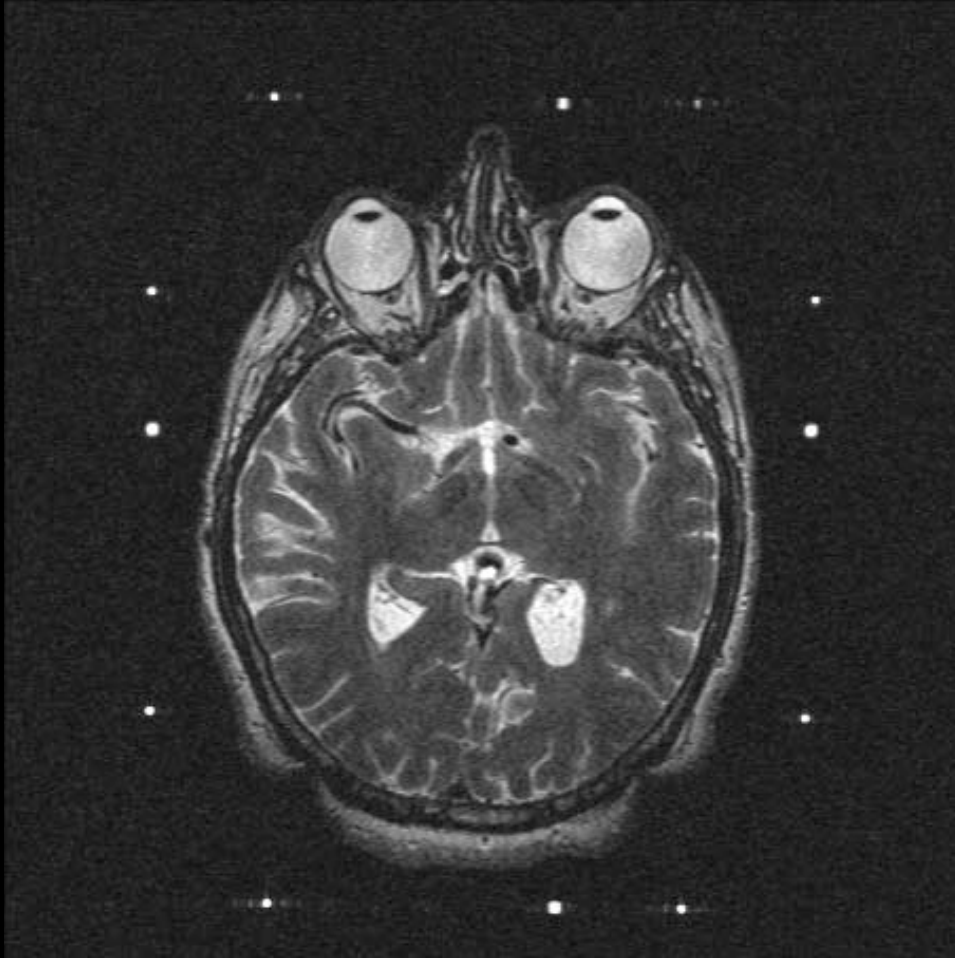
Principles of stereotaxy: Imaging



Principles of stereotaxy: Imaging



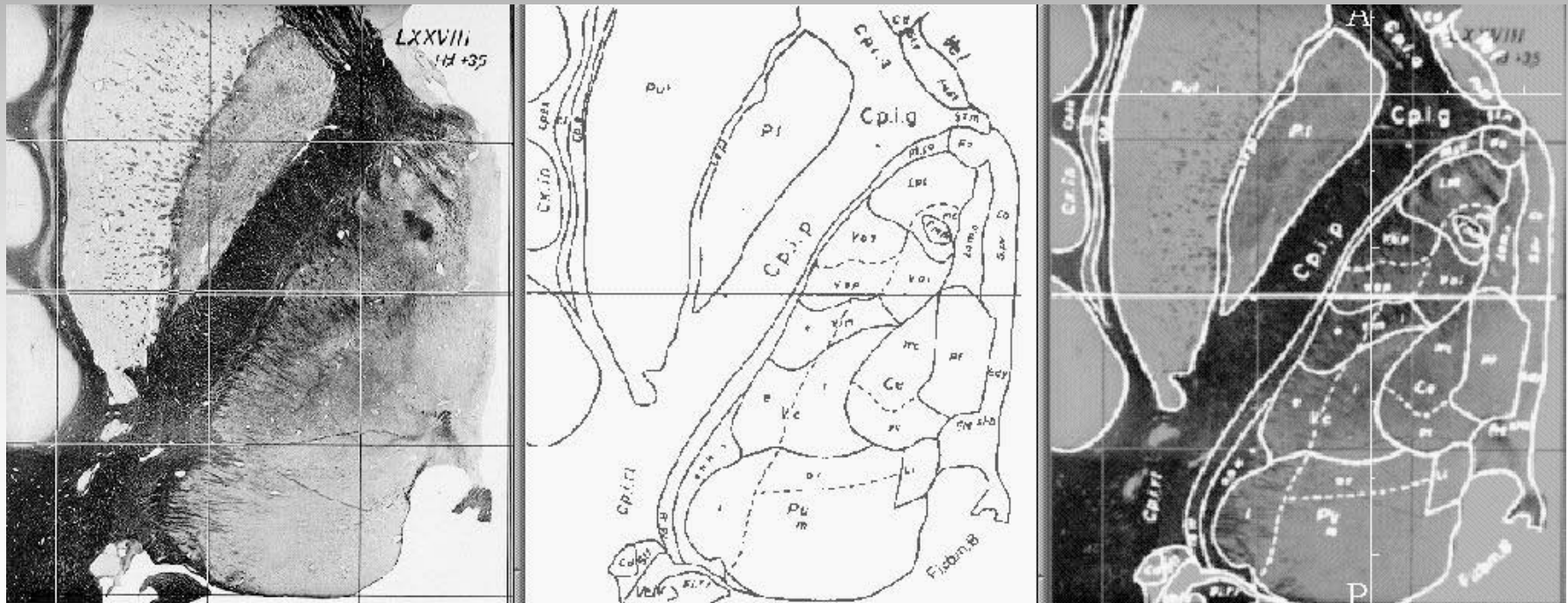
Principles of stereotaxy: Imaging



What if you cannot see your target?

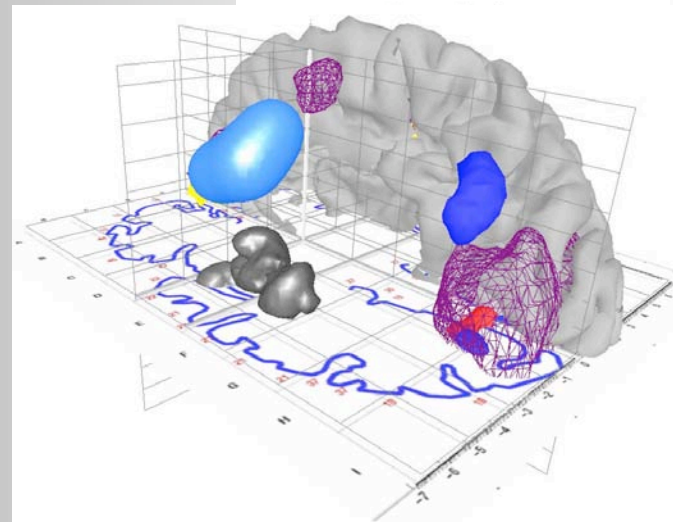
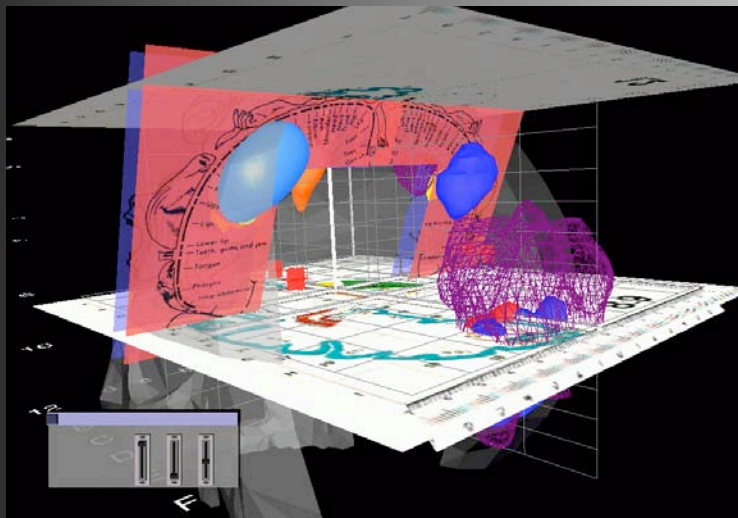
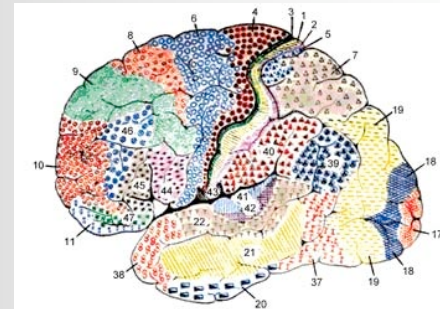
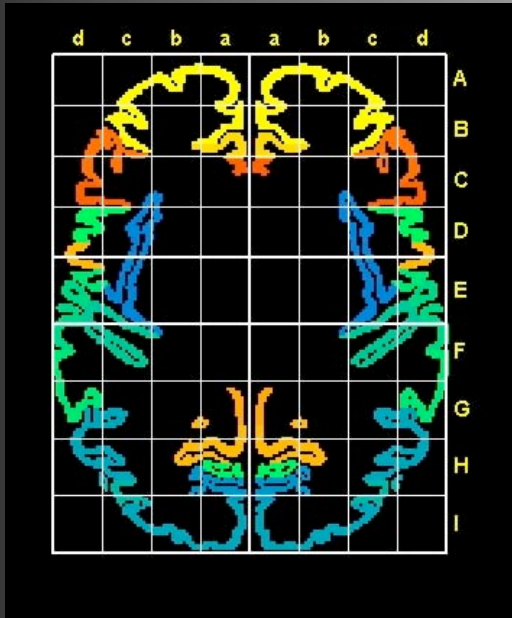
Brain atlases

- ⚡ Schaltenbrand & Bailey 1959
- ⚡ Schaltenbrand & Wahren, 1977



Brain atlases

⚡ Talairach & Tournoux, 1988



Brain atlases: Integration with MRI



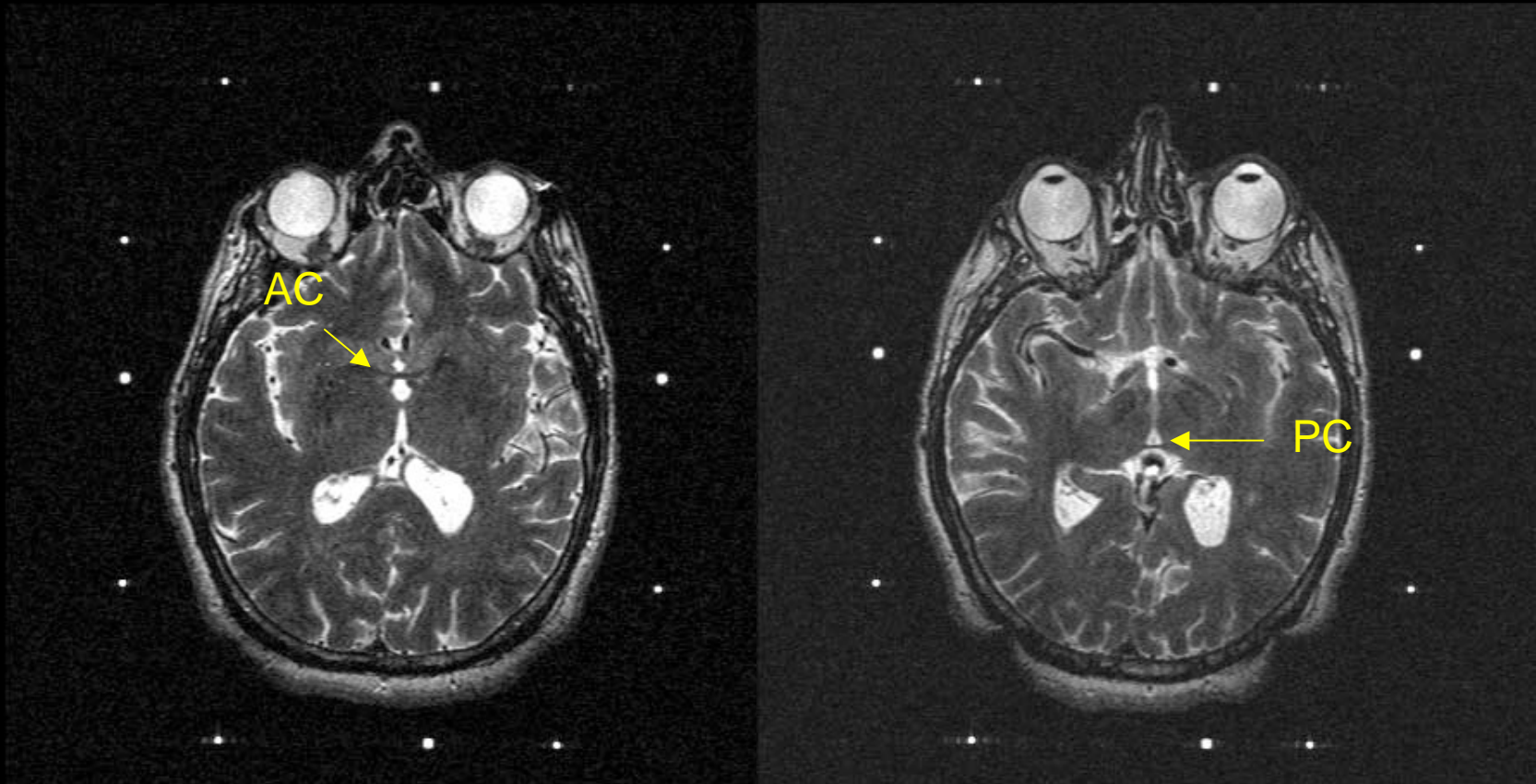
Brain atlases: Are they good enough?

How do you relate atlas to your patient?

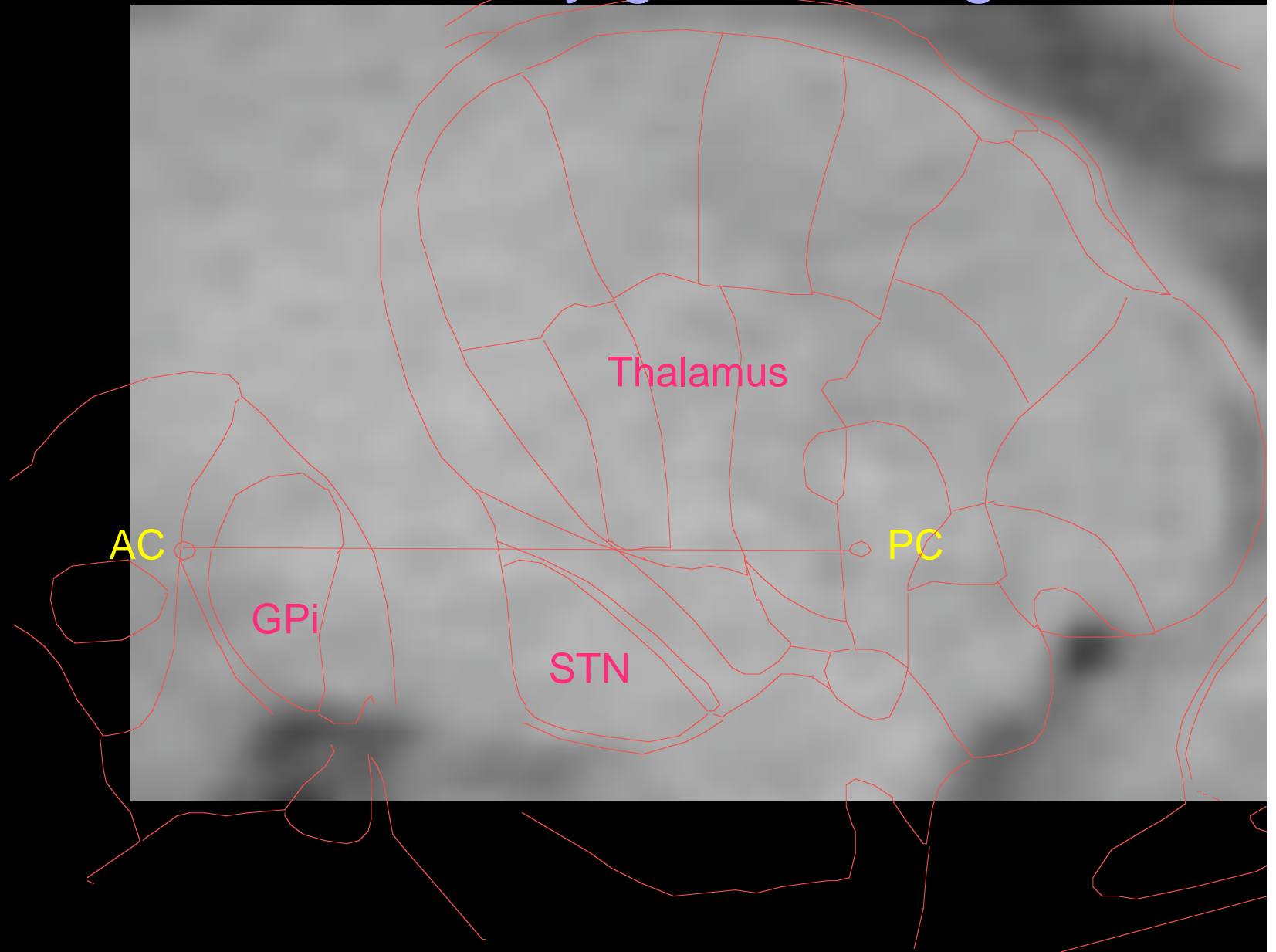
- ⚡ Linear 1-d deformation based on AC-PC line
- ⚡ Linear 2-d deformation based on height of thalamus
- ⚡ Dynamic warping?

What if your target is 4 x 6 x 6 mm

Brain atlases: Are they good enough?



Brain atlases: Are they good enough?



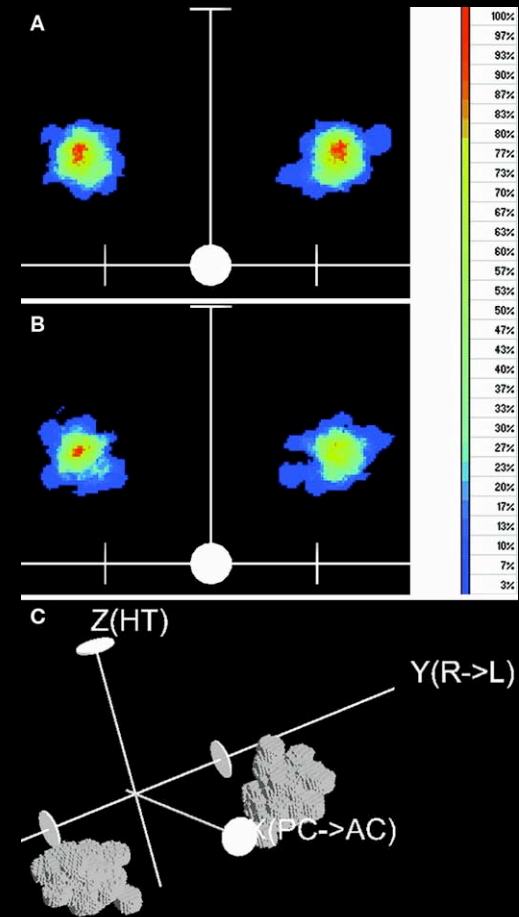
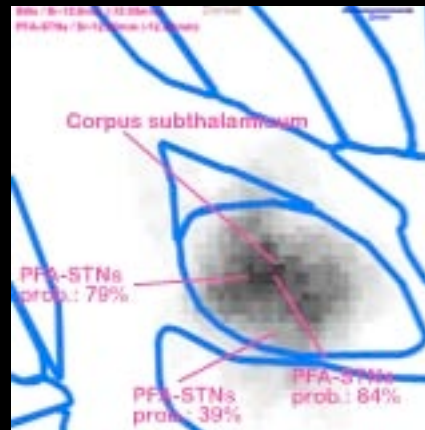
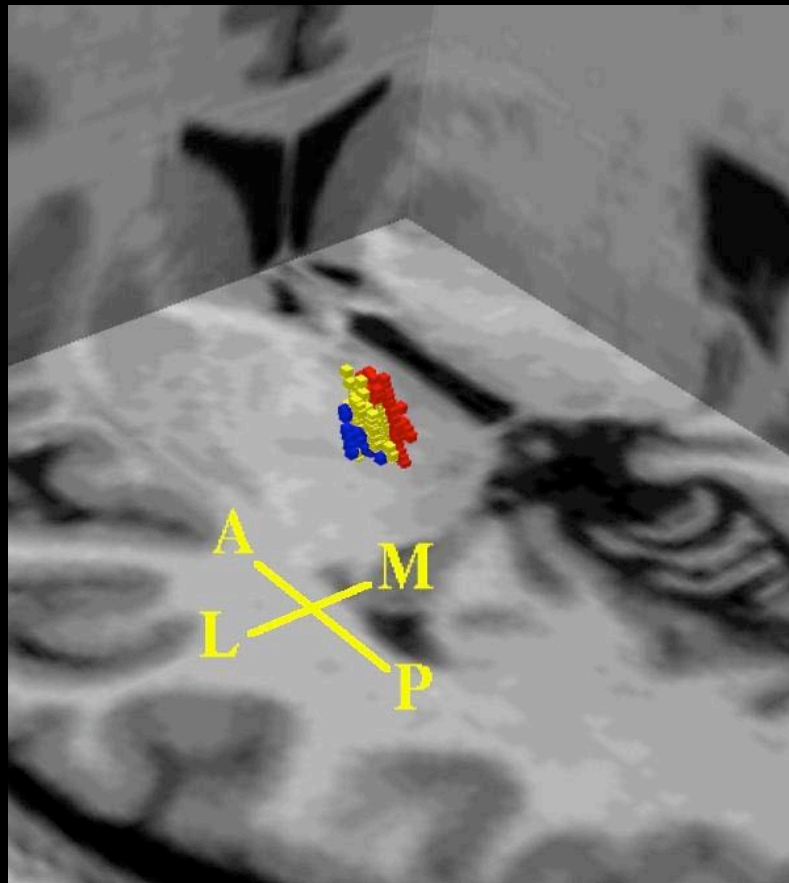
Outline

⚡ Principles of functional neurosurgery

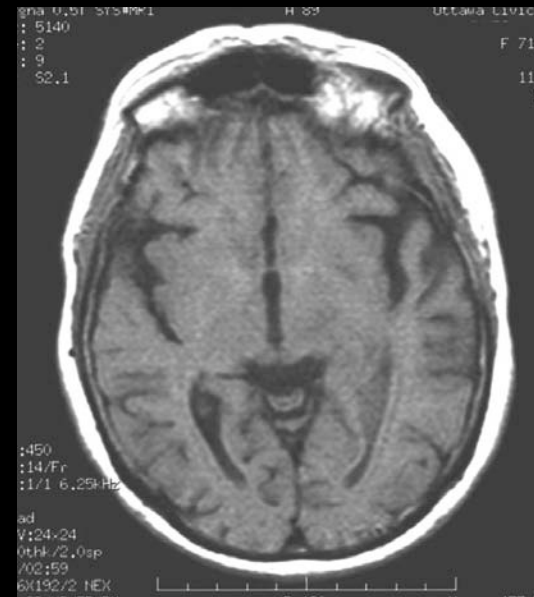
Electrophysiology = “function”

New attempts to marry imaging and function: fMRI, probabilistic atlases, brain warping algorithms

To marry imaging and function

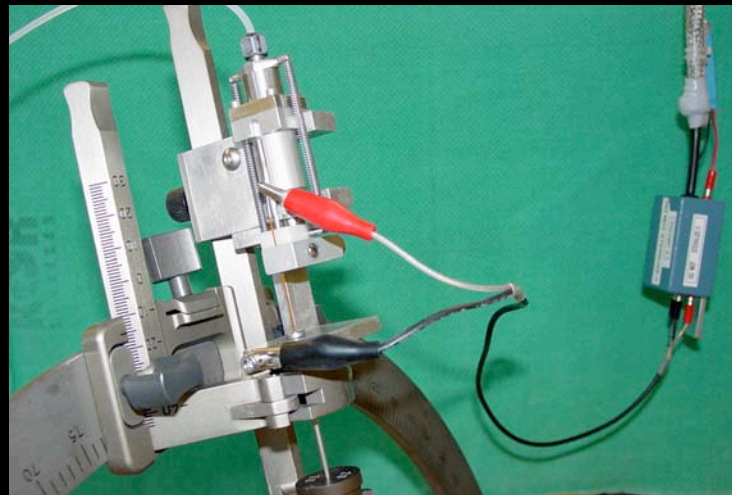
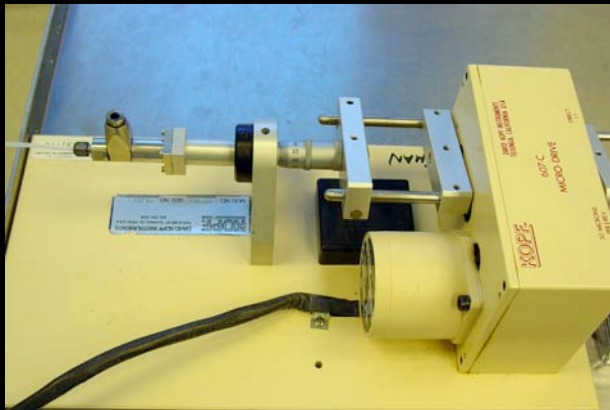
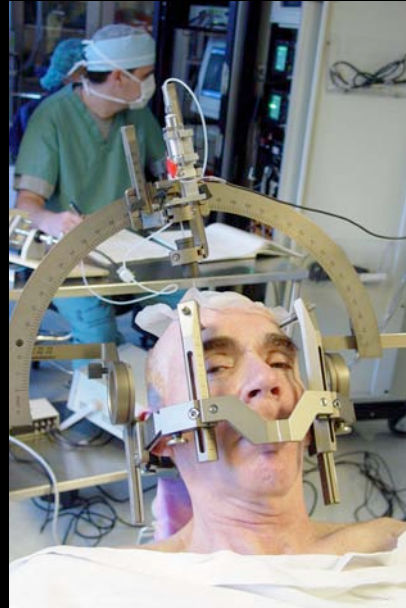
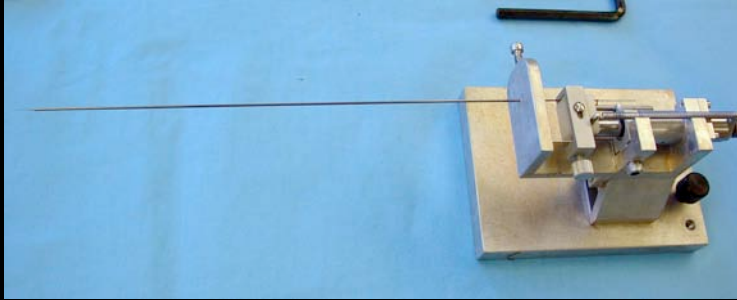


Imaging & atlases: Are not good enough



- ⚡ stereotactic frame placement
- ⚡ **imaging** to determine **tentative target**
- ⚡ physiological monitoring to confirm correct target
- ⚡ implant the DBS electrode or make an RF lesion

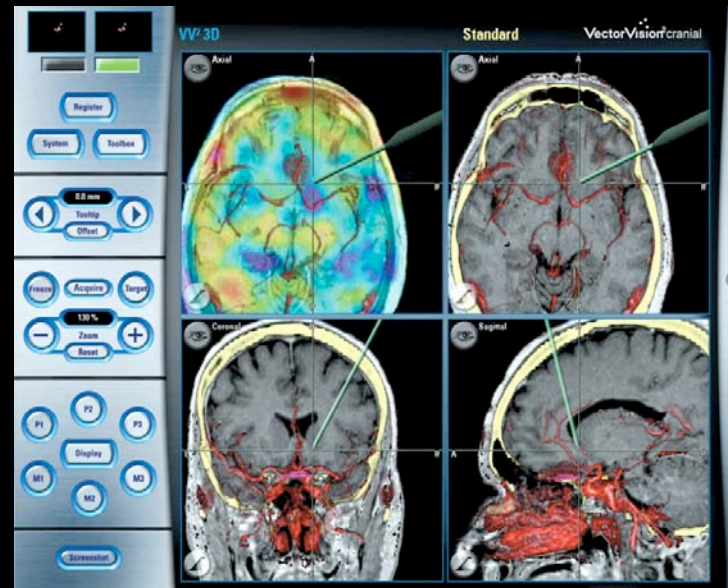
Microelectrode methods



Outline

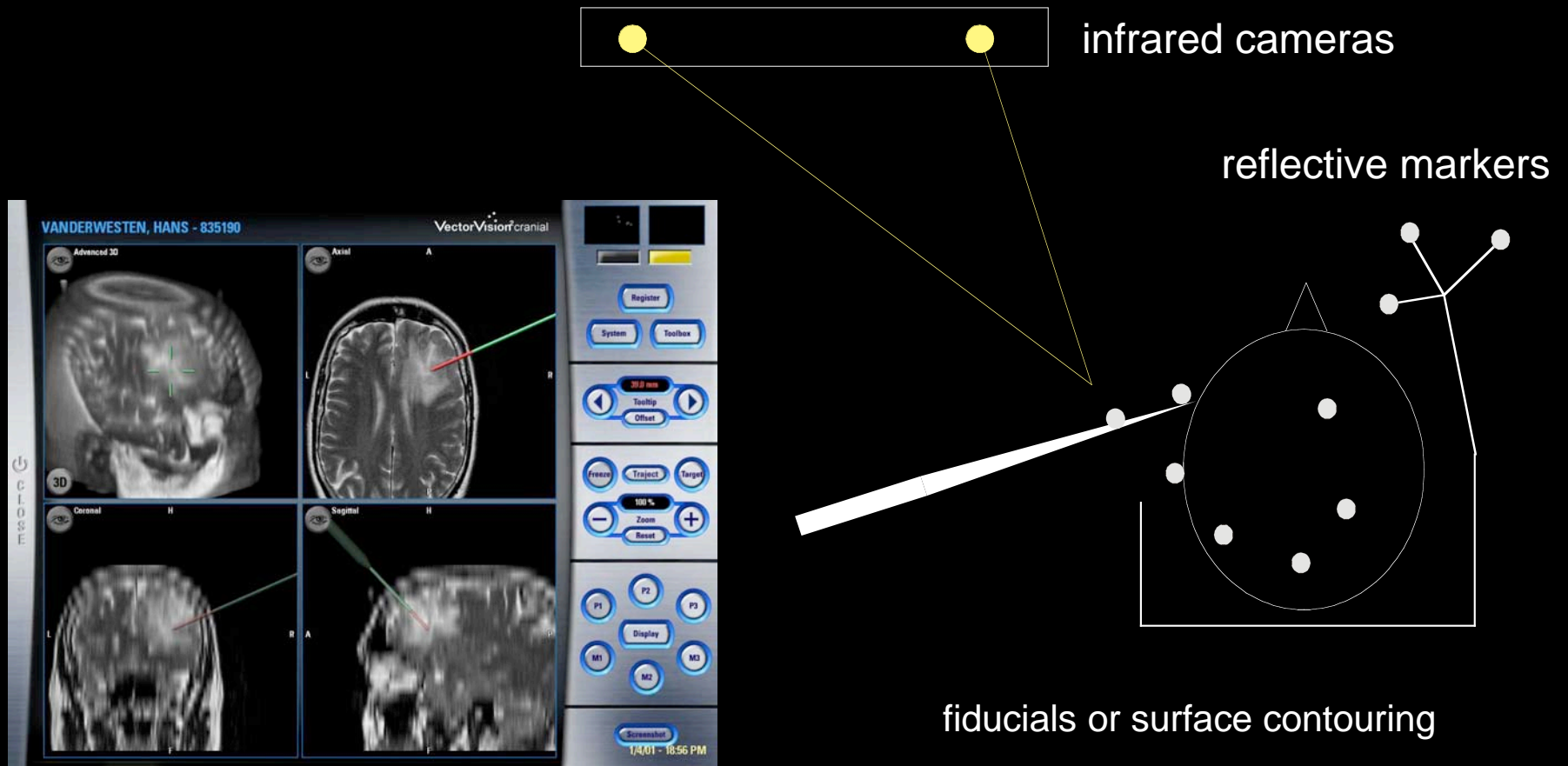
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- ⚡ **“Frameless” image-guided neurosurgery**
- ⚡ Psychosurgery
- ⚡ Principles of stereotactic radiosurgery

Principles of stereotaxy: “Frameless” systems



- ⚡ “Image-guided” surgery but all require a “frame”
- ⚡ Based on principle of triangulation, relationship between fiducials/surface contouring imaged, then wand and star with reflective markers and 2 infrared cameras

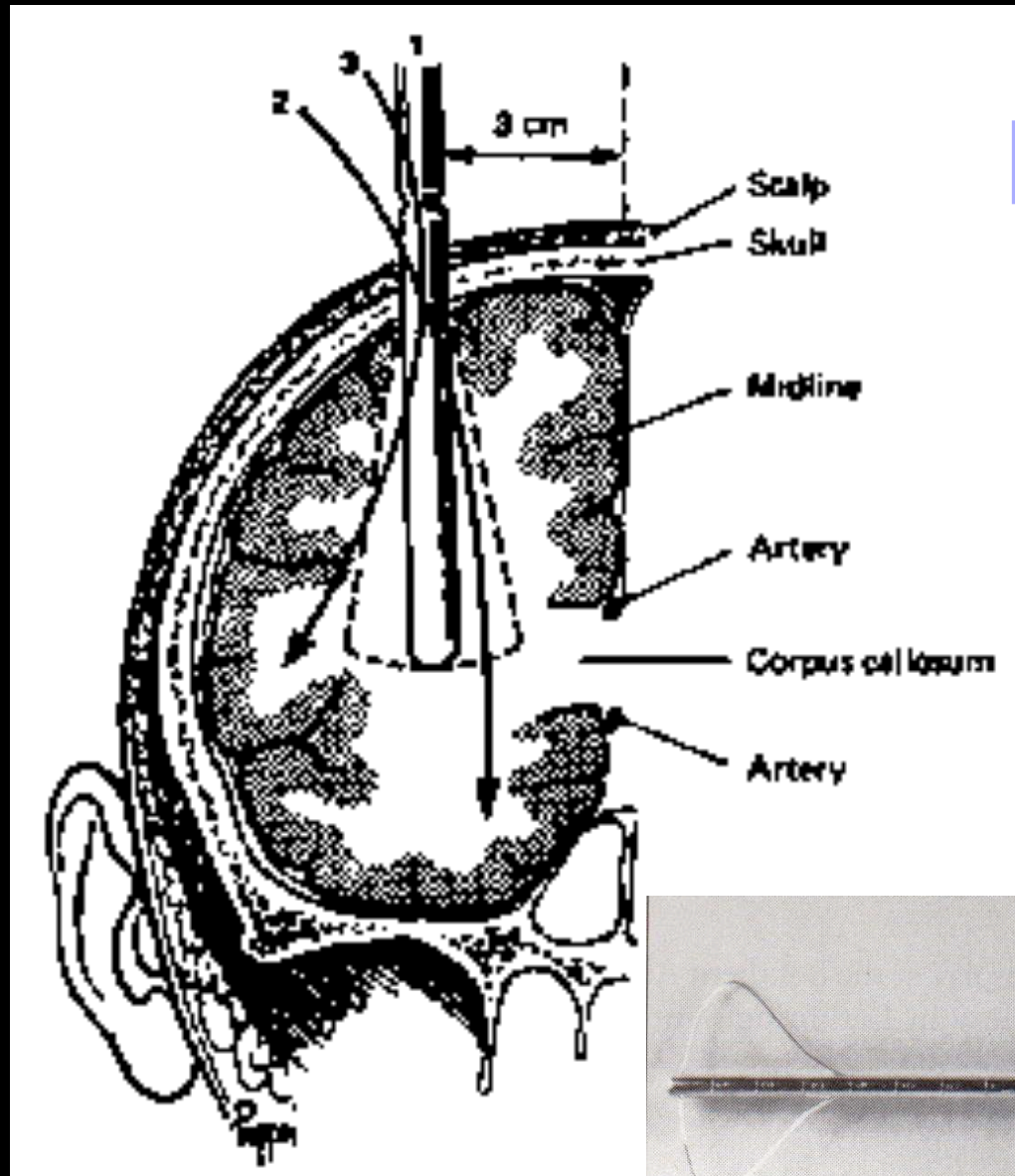
Principles of stereotaxy: "Frameless" systems



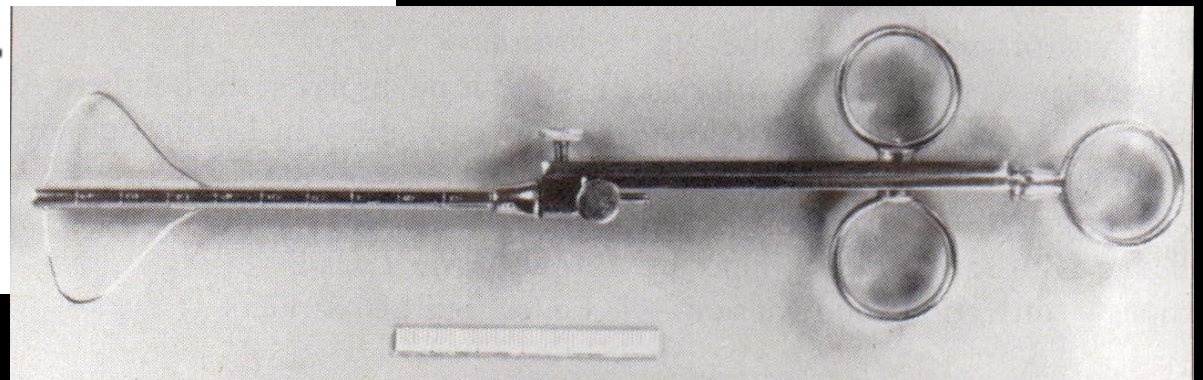
Outline

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- ⚡ **Psychosurgery**
- ⚡ Principles of stereotactic radiosurgery

Psychosurgery



- ⚡ Prefrontal leukotomy
- ⚡ Anterior capsulotomy
- ⚡ Cingulotomy
- ⚡ Subcaudate tractotomy
- ⚡ Limbic leukotomy



History



- ⚡ Egas Moniz:
Tentatives opératoires dans le traitement de certaines psychoses, 1936
- ⚡ Nobel Prize, 1947:
Prefrontal Leucotomy
- ⚡ 10,000 operations pre-1949 in USA

Adapted from A. Abosch 2001

Therapeutic alternatives for psychotic patients pre-1936

- ⚡ Restraints
- ⚡ Immersion baths
- ⚡ Insulin coma
- ⚡ Seizure induction



Adapted from A. Abosch 2001

Outcomes of prefrontal lobotomies

Tooth & Newton (1961)

⚡ N=10,365

- ⚡ 70% “improvement”
- ⚡ 6% mortality
- ⚡ 1% epilepsy
- ⚡ 1.5% marked disinhibition

Freeman & Watts:
Trans-orbital Leucotomy
“ice-pick procedure”



Adapted from A. Abosch 2001

Societal Disenchantment with Psychosurgery



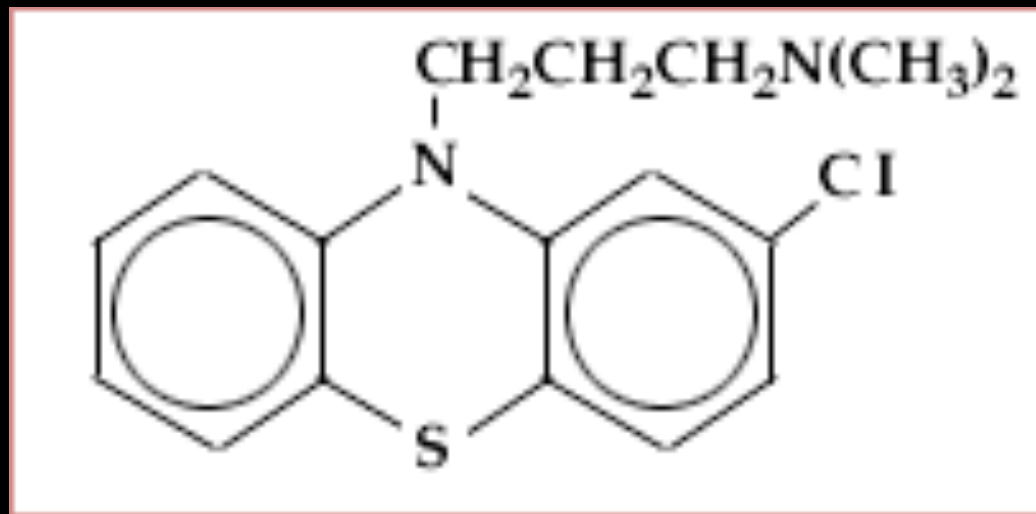
Fannie Farmer
...and other prominent people
who were permanently
altered by surgery

*One Flew Over the
Cuckoo's Nest, 1958*



Adapted from A. Abosch 2001

Chlorpromazine (1952):
Delay & Deniker

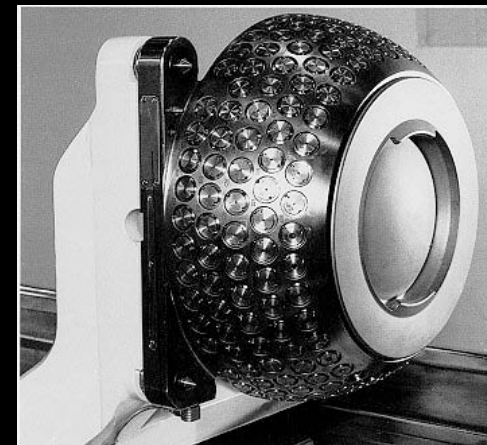
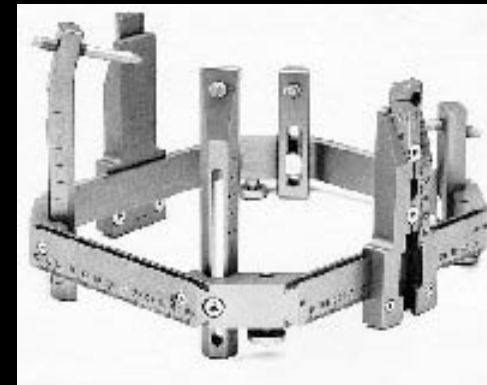


- ⚡ First neuroleptic
- ⚡ First effective treatment for psychiatric disease

Adapted from A. Abosch 2001

“Modern” Psychosurgery

- ⚡ Refinements in stereotactic technique
- ⚡ Refractory OCD & Severe Depression remain indications



Gamma Knife Radiation Helmet

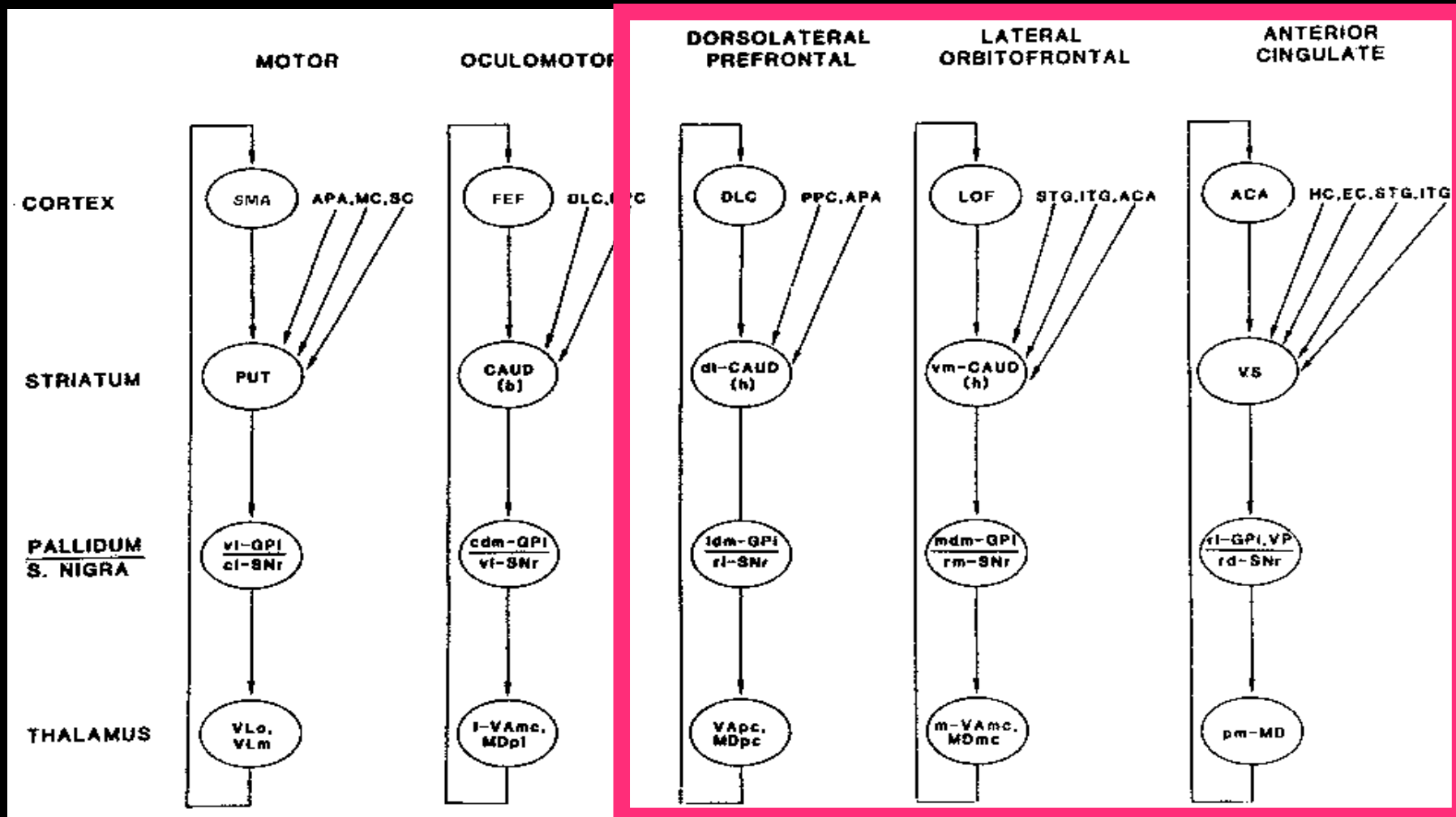
Adapted from A. Abosch 2001

Rationale

- ⚡ 1936—Initial report on prefrontal lobotomy (Moniz)
- ⚡ 1937—"A Proposed Mechanism of Emotion (Papez)
- ⚡ 1952—Limbic system expanded (McLean)
- ⚡ Limbic system connects somatic & visceral stimuli/responses w/higher cortical function

Adapted from A. Abosch 2001

Anatomical Rationale



Fronto-striato-pallido-thalamic-frontal loop

DSM-IV Criteria for OCD

- Presence of *either* obsessions or compulsions or both
- These cause marked distress, are time consuming (>1 hr/day), significantly interfere with normal routine, occupational or academic functioning, or social relationships

Adapted from A. Abosch 2001

Obsessions....

- ⚡ recurrent & persistent thoughts, impulses, or images, intrusive & inappropriate, causing marked anxiety/distress
- ⚡ attempts to ignore/suppress such thoughts, impulses, images, or to neutralize with other thought or action

Adapted from A. Abosch 2001

Compulsions...

- ⚡ repetitive behaviors (e.g., hand washing, ordering, checking) or mental acts (e.g., praying, counting, repeating words silently) patient feels compelled to perform in response to an obsession
- ⚡ behaviors/mental acts are aimed at preventing/reducing distress or preventing some dreaded situation; behaviors/mental acts are unconnected w/ what they're designed to prevent or are clearly excessive

Adapted from A. Abosch 2001

Quantitative OCD Assessment

⚡ Yale-Brown OCD Scale (YBOCS)*

⚡ 0-7 Subclinical

⚡ 8-15 Mild

⚡ 16-23 Moderate

⚡ 24-31 Severe

⚡ 32-40 Extreme

Consider surgery

⚡ A scale to rate severity of OCD

Goodman et al, Arch Gen Psychiatry. 1989; 46:1006-1011

Adapted from A. Abosch 2001

Treatment of OCD

- ⚡ *Majority* of patients respond to behavioral and/or medical therapy:
 - ⚡ Clomipramine (SRI) & selective serotonin reuptake inhibitors (SSRIs), e.g. fluoxetine, sertraline
- ⚡ Only *small %* remain refractory & severely disabled

Adapted from A. Abosch 2001

Criteria for Surgery

- ⚡ Fulfills DSM-IV criteria for OCD
- ⚡ Significant suffering: YBOCS ≥ 20
- ⚡ Significant reduction in psychosocial functioning
- ⚡ Patient himself requests surgery, provides informed consent
- ⚡ Failure of *adequate trial* of therapy

Adapted from A. Abosch 2001

Adequate Trial of Therapy

- ⚡ ≥ 10 wks of maximally tolerated doses of clomipramine & 3-4 SSRIs
- ⚡ Behavioral therapy
- ⚡ In practice ≥ 5 yrs of intensive psychiatric treatment
- ⚡ Series of iv enafranil

Adapted from A. Abosch 2001

Relative Contraindications

- ⚡ Age < 18 yo
- ⚡ Concurrent diagnoses, such as
 - ⚡ Substance abuse
 - ⚡ Organic brain syndrome
 - ⚡ Delusional disorder
 - ⚡ Personality disorder
 - ⚡ Mental retardation
- ⚡ Lack of social support

Adapted from A. Abosch 2001

Preoperative Evaluation

- ⚡ Multidisciplinary Case Review Committee
 - ⚡ Neuropsychiatry, Neurosurgery, Clinical Psychology, Hospital Ethics, Social Work
- ⚡ Anatomical MRI
- ⚡ Neurocognitive Assessment
- ⚡ fMRI and/or PET—research tools

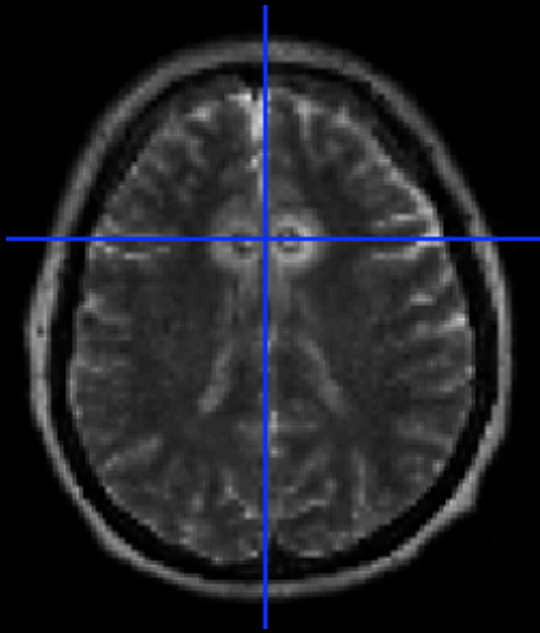
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Current Procedures

1. Cingulotomy
2. Anterior Capsulotomy
3. Subcaudate Tractotomy
4. Limbic Leucotomy

Adapted from A. Abosch 2001

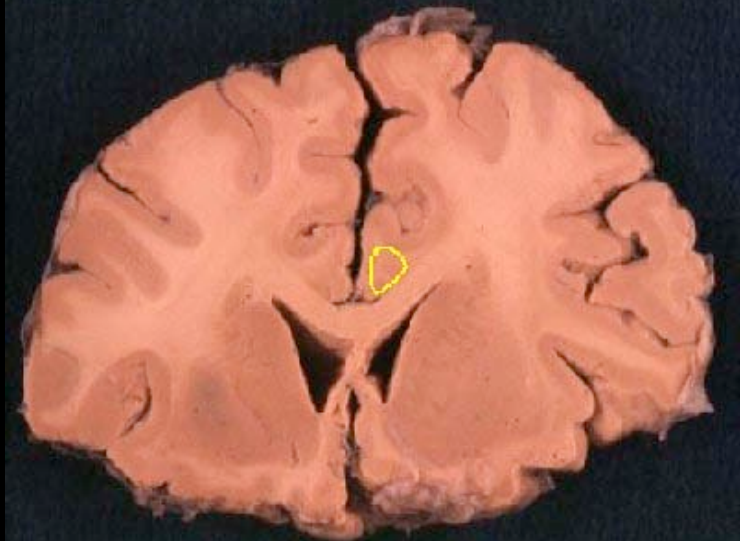
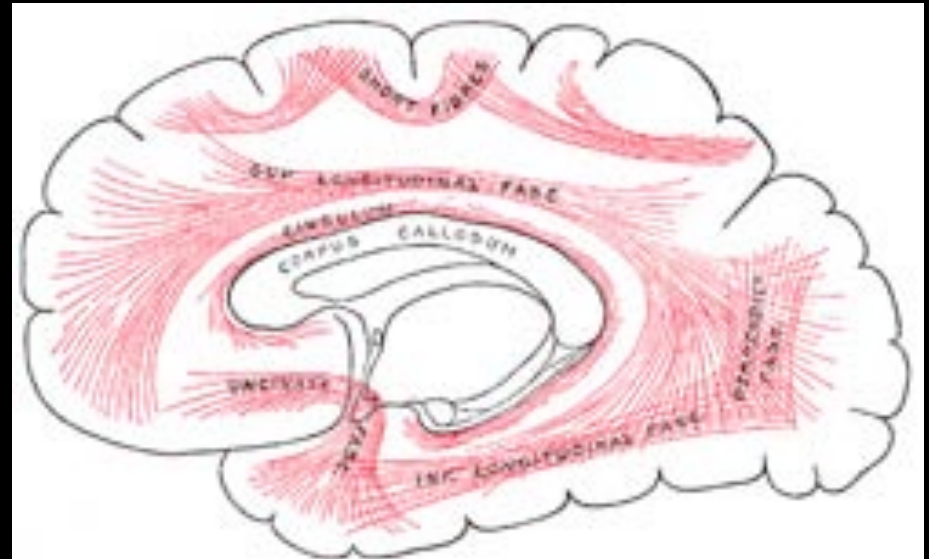
Cingulotomy



Foltz & White (1962)

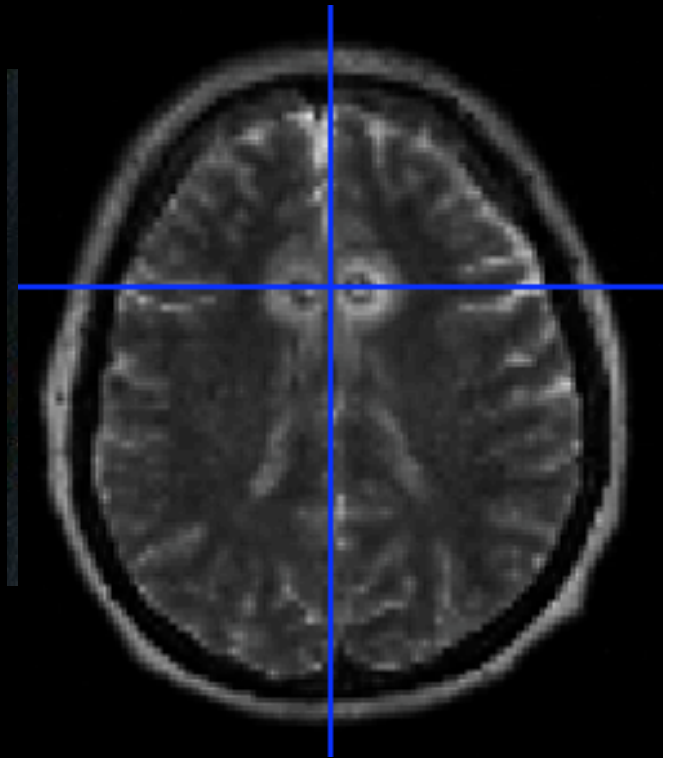
Target:

- ⚡ 20 mm posterior to anterior-most tip of frontal horn
- ⚡ 7 mm lateral to midline



Anterior Cingulotomy

- ⚡ Also used in treatment of pain & major depression
- ⚡ Most commonly performed in North America for OCD & depression



Adapted from A. Abosch 2001

Anterior Cingulotomy: Results

- ✦ Ballantine et al., 1987:
 - ✦ N=198, mean f/u 8.6 y
 - ✦ 62% severe affective d/o improved
 - ✦ 56% OCD improved
- ✦ Jenike & Baer, 1991:
 - ✦ N=33 with OCD
 - ✦ 25-30% significant improved (YBOCS)
- ✦ Baer et al, 1995:
 - ✦ N=18, 27 m f/u
 - ✦ Prospective, non-blinded
 - ✦ Only 28% responders (YBOCS)
 - ✦ No serious adverse effects

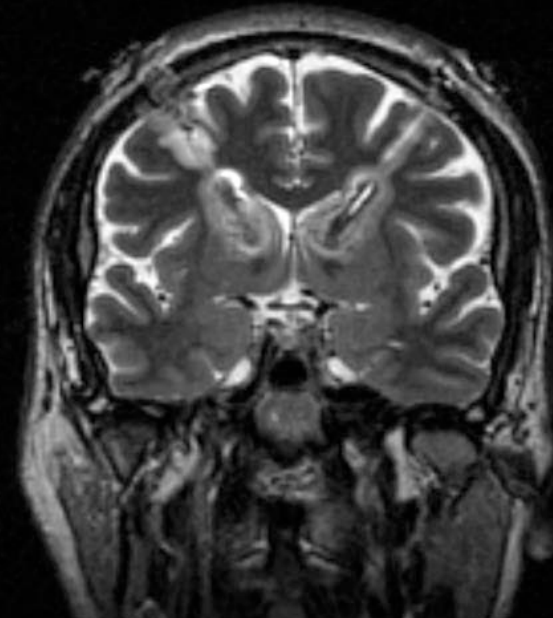
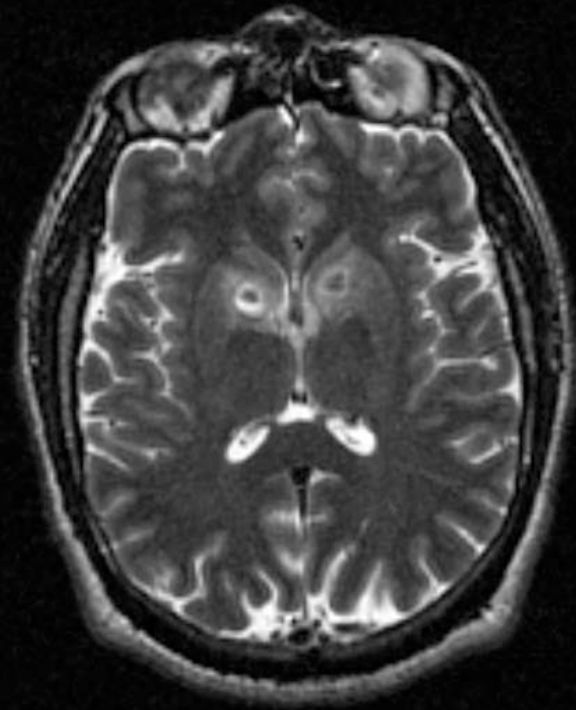
Adapted from A. Abosch 2001

Anterior Capsulotomy

Lars Leksell (1972)

Target: anterior limb of internal capsule

- ⚡ Lesion ~18 mm in length
- ⚡ 5 mm behind tip of frontal horn, 20 mm lateral or halfway between frontal horn tip and foramen of Munro
- ⚡ At level of foramen of Munro
- ⚡ At the border between putamen and pallidum



Anterior Capsulotomy: Results

- ⚡ Mindus et al, 1997:
 - ⚡ 19 OCD pts, 8.4yrs median f/u (Sweden)
 - ⚡ 47% good outcome
 - ⚡ 19 transient confusion
 - ⚡ 1 seizure
 - ⚡ 1 suicide
 - ⚡ 2 patients slovenly
 - ⚡ Weight gain of 10%

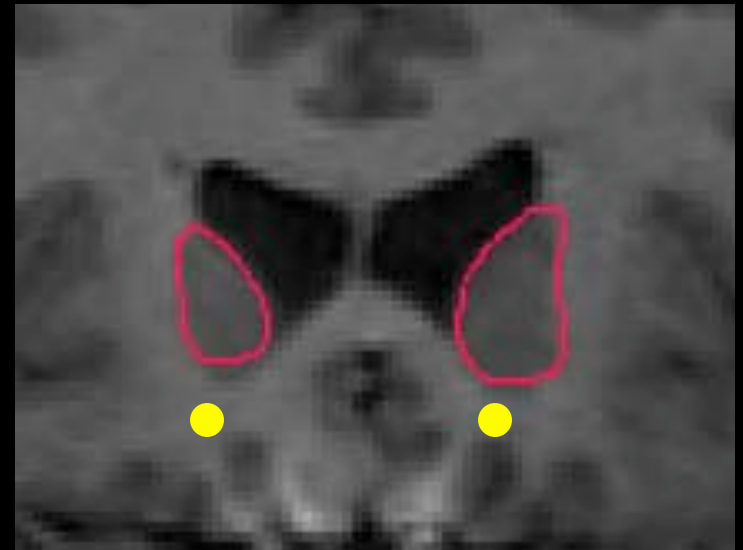
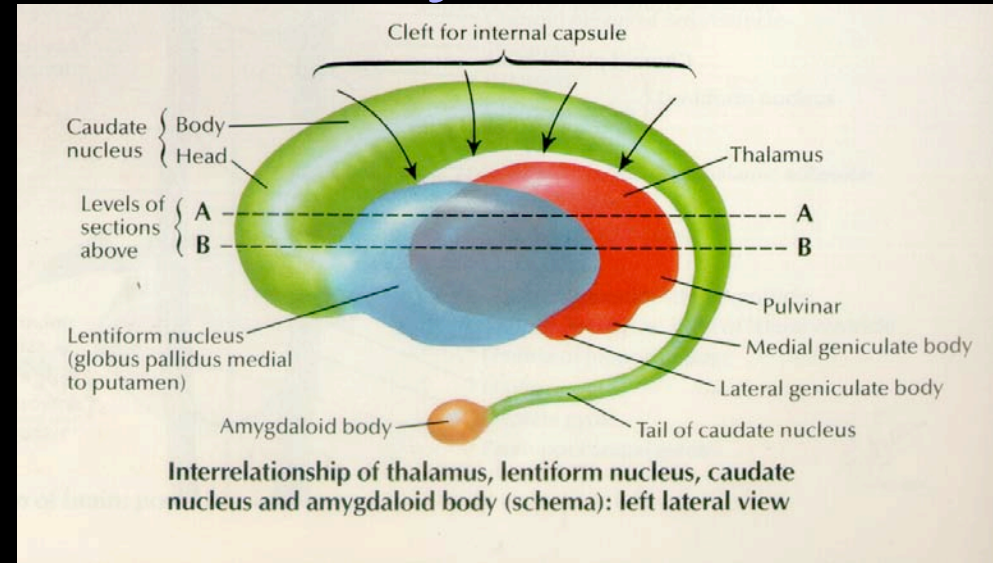
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Subcaudate Tractotomy

Knight (1964)
Stereotactic yttrium

Target

- ⚡ ventral to caudate head = substantia innominata (15 mm lat, 10 mm dorsal to planum sphenoidale)
- ⚡ Intra-operative stimulation produced autonomic responses



Subcaudate Tractotomy: Results

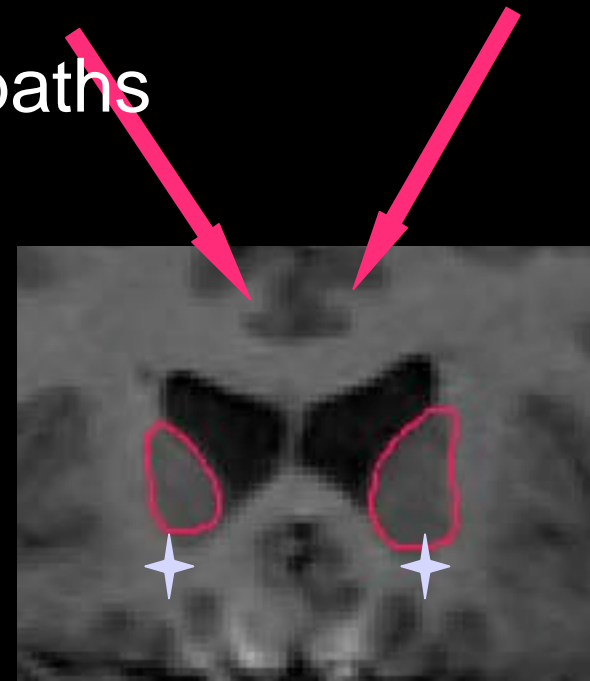
⚡ Goktepe 1975:

- ⚡ 208 pts mean 2.5 yr f/u
- ⚡ 68% depressed pts improved
- ⚡ 50% OCD pts improved
- ⚡ Schizophrenics, personality disorders, substance abuse patients did poorly
- ⚡ Seizures 2.2%
- ⚡ Undesirable personality traits 6.7%
- ⚡ 1 death from hypothalamic destruction
- ⚡ 3 suicides
- ⚡ Not usually performed in North America

Adapted from A. Abosch 2001

Limbic Leucotomy

- ⚡ Kelley et al. (London, 1973)
- ⚡ ~10 targets within subcaudate + anterior cingulate region
 - ⚡ SCT → disconnects OFT paths
 - ⚡ AC → disconnects Papez
- ⚡ Not commonly performed in North America



Adapted from A. Abosch 2001

Limbic Leucotomy: Results

- ⚡ Kelley, 1973:
 - ⚡ N=66, mean f/u 16 m
 - ⚡ 89% of OCD pts improved
 - ⚡ 78% of depressed pts improved
 - ⚡ 80% of schizophrenics improved
 - ⚡ lethargy, confusion, lack of sphincter control common post-op, but resolves
 - ⚡ No post-op seizures

Adapted from A. Abosch 2001

Problems with Literature

- ⚡ Previously no standardized rating scale for pre- & post-operative assessment
- ⚡ DSM criteria for diseases have changed some over the years
- ⚡ No blinding of studies (patients or investigators)

Adapted from A. Abosch 2001

Risks of NOT intervening

- ⚡ Suicide risk among patients with refractory OCD is high
- ⚡ Incalculable loss of psychosocial functioning

Adapted from A. Abosch 2001

Psychosurgery: Conclusions

- ⚡ Surgical treatment of refractory OCD can be helpful in ~28% pts, with minimal risks
- ⚡ Optimal target unknown
- ⚡ Surgery is only one aspect of the entire treatment/rehab plan
- ⚡ Psychosurgery should be performed only at specialized sites

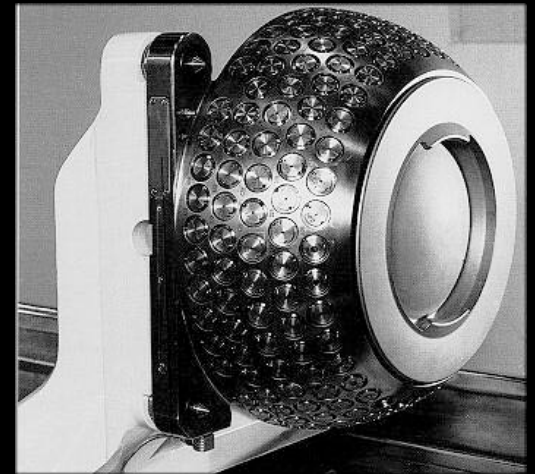
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What is SRS

- ⚡ Leksell performed first stereotactic treatment in 1951 (linear accelerator-based, with cross-fired arcs), developed the Gamma knife in 1968
- ⚡ Proton-beam radiosurgery started in 1956
- ⚡ Linac-based radiosurgery established in early 1980s



SRS: Current Indications

Benign Lesions:

- ⚡ AVMs
- ⚡ Acoustic Neuromas
- ⚡ Meningiomas
- ⚡ Pituitary adenomas

Malignant Lesions:

- ⚡ Metastases
- ⚡ Gliomas?

Functional Lesions:

- ⚡ Trigeminal neuralgia
- ⚡ Epilepsy ?
- ⚡ Chronic pain ?



Radiotherapy: Options

Single fraction SRS

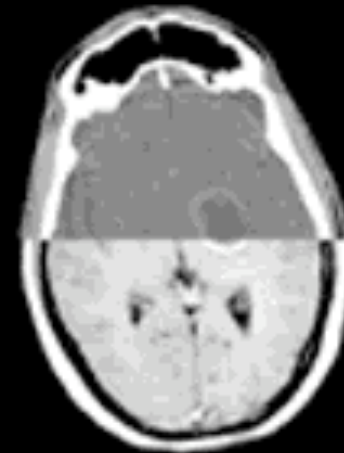
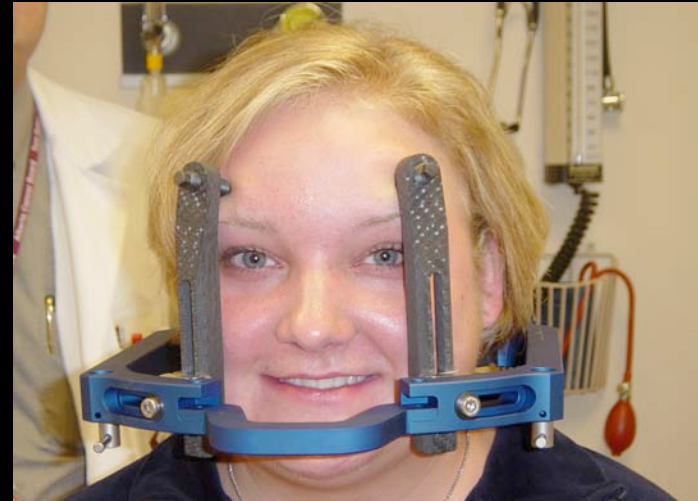
- ✦ 1 extremely high dose of radiation
- ✦ Ablative ~ surgical excision
- ✦ Most appropriate for
 - ✦ Arterio-venous malformations
 - ✦ Benign lesions: acoustic neuromas, pituitary adenomas, meningiomas
 - ✦ Functional targets: trigeminal neuralgia, epilepsy, pain

Fractionated stereotactic radiation therapy

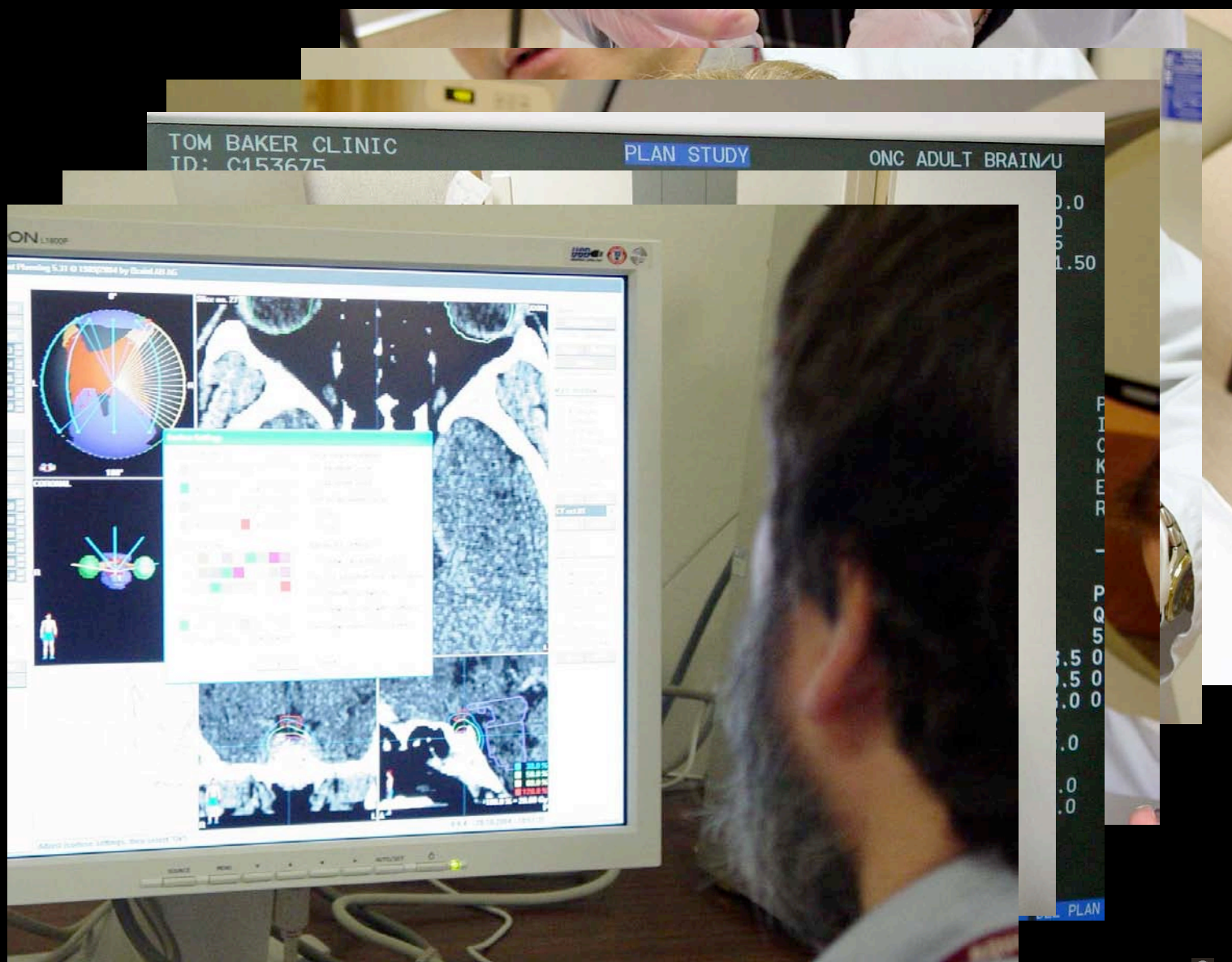
- ✦ Many small doses of radiation given over many days
- ✦ Preferentially spares late-responding *i.e.* normal tissue resulting in higher therapeutic gain
- ✦ Equivalent to true radiation therapy
- ✦ Most appropriate for malignant tumors

Radiotherapy: Single treatment SRS

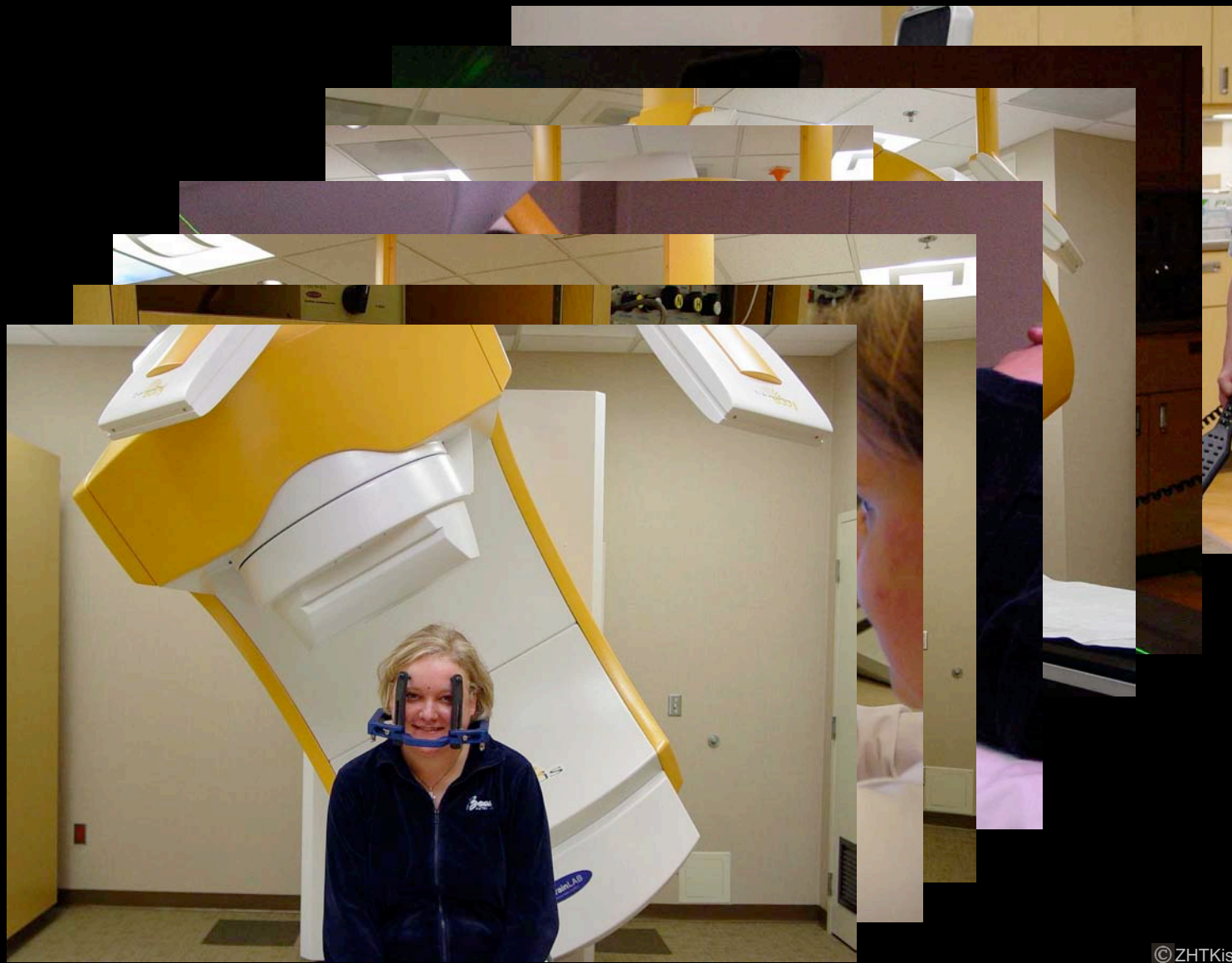
- ⚡ Fixed immobilization device
 - ⚡ Ensures maximum precision
- ⚡ Same day planning performed based on fine cut CT scan +/- MRI scan
- ⚡ Patient treated same day



The Process: Treatment day

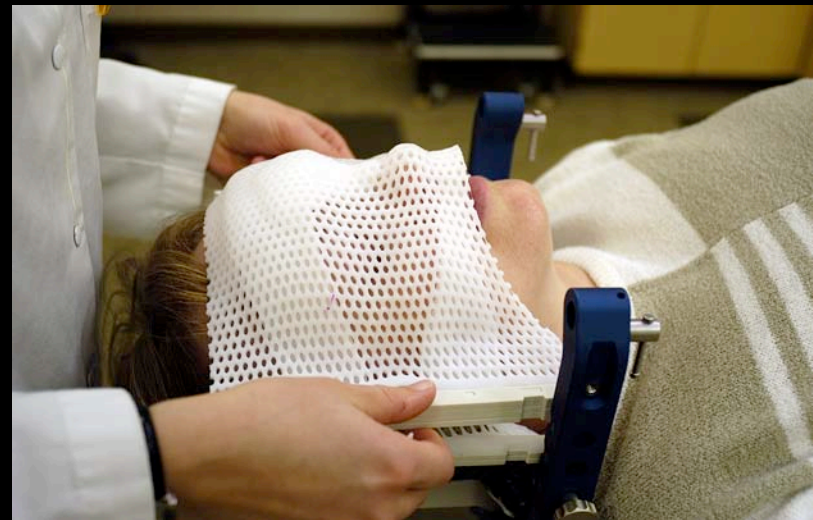


The Process: Treatment day

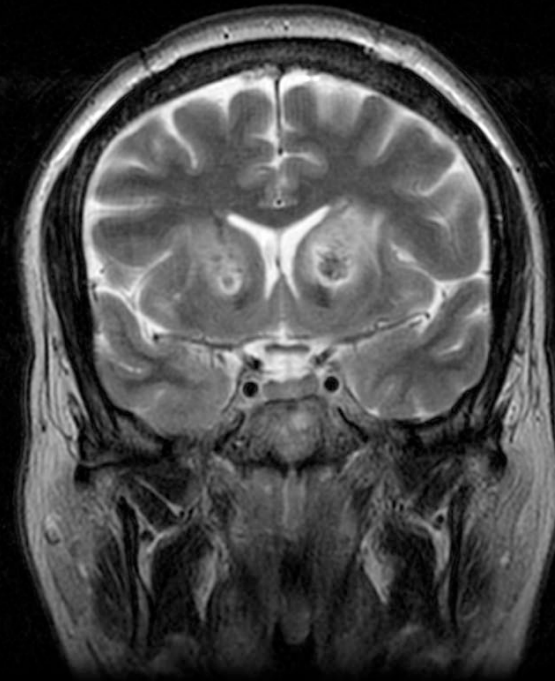
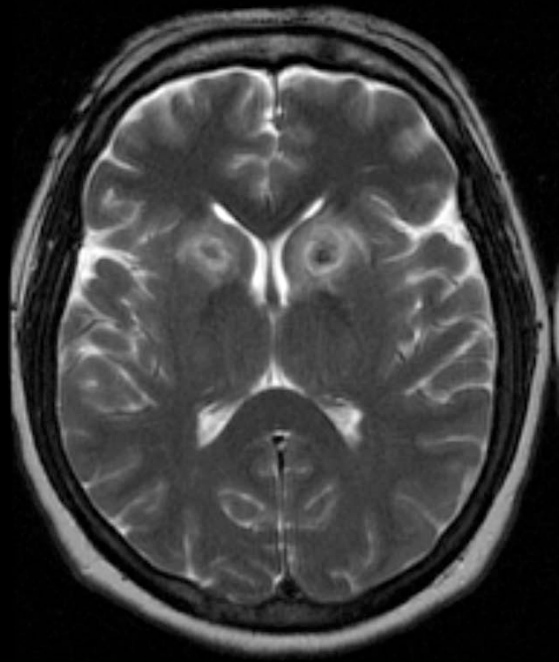


Radiotherapy: Fractionated treatments

- ⚡ Relocatable frame
- ⚡ Planning based on fine-cut CT scan +/- MRI scan
- ⚡ Patient comes for daily treatments over the course of several weeks



Or the target must be huge

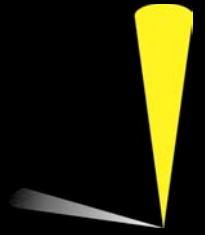


Novalis

- ? Radiation beam shaping with micro-multileaf collimator

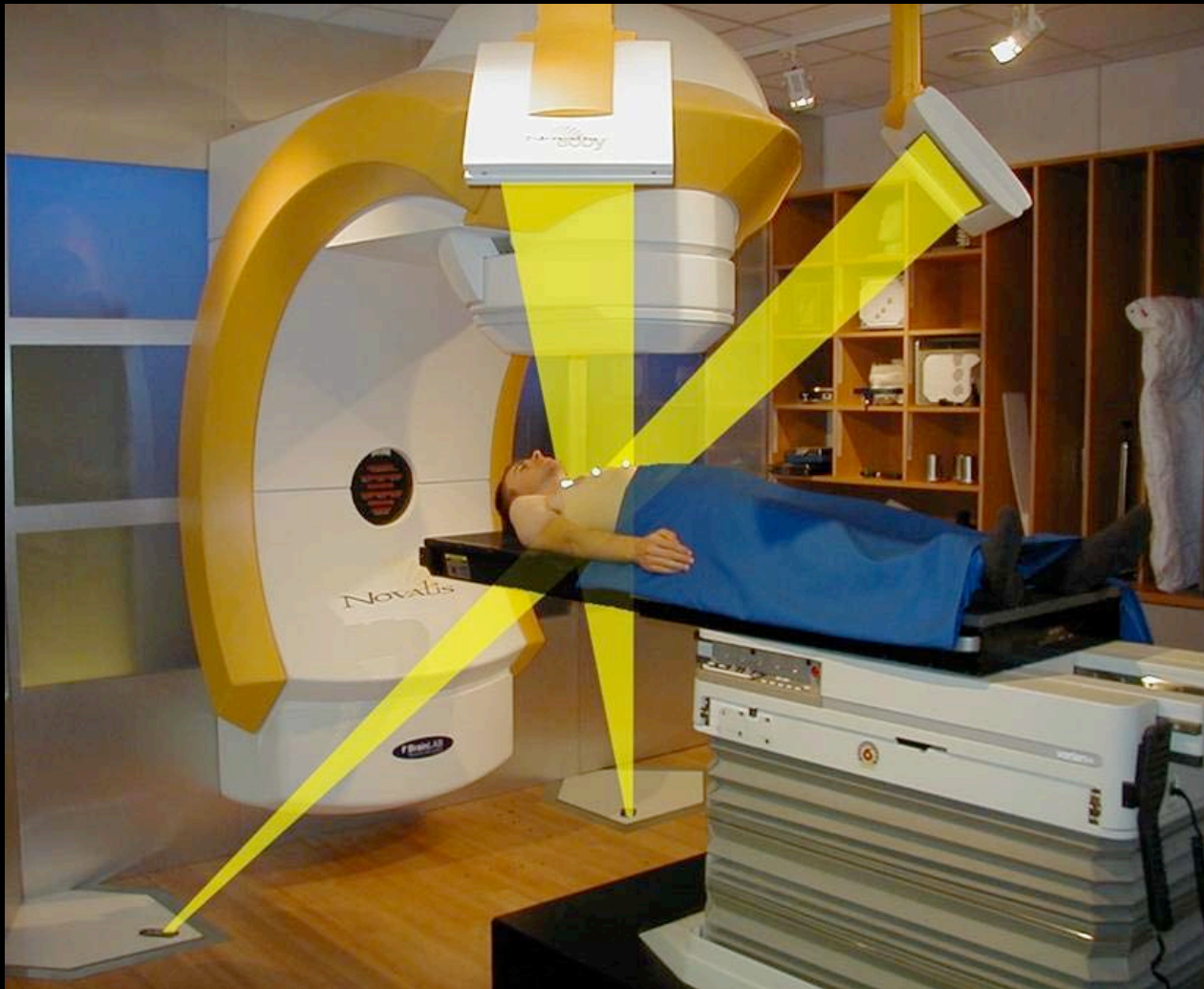


Novalis



- ? Micro-multileaf collimator allows IMRS and IMRT
- ? High dose rate (800 cGy/min)
- ? Allows use of fractionation: basic radiobiology principle that improves preservation of normal tissue passing through radiated field (e.g. acoustics, cavernous sinus lesions)
- ? Use outside the head (e.g. spine)
- ? On-line X-ray monitoring of patient movement

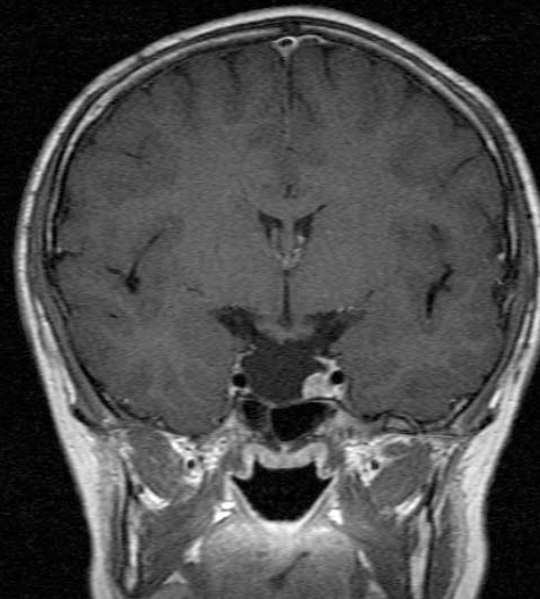
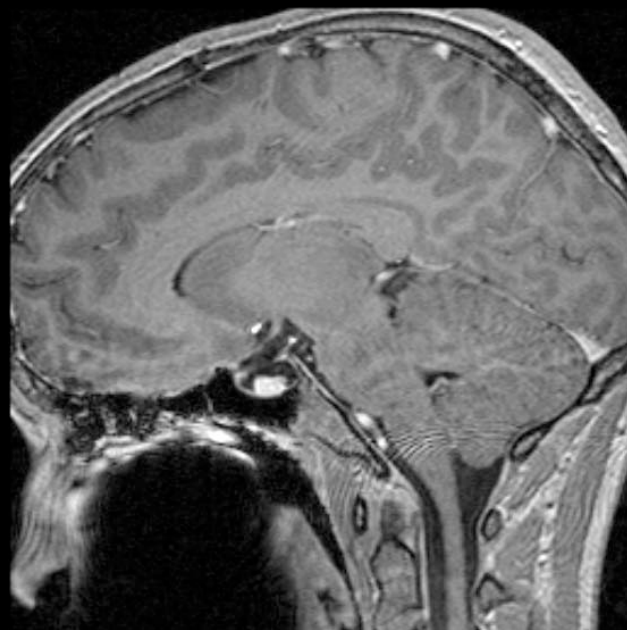
Novalis



Case 1

14 yo male with 1 cm recurrence of craniopharyngioma

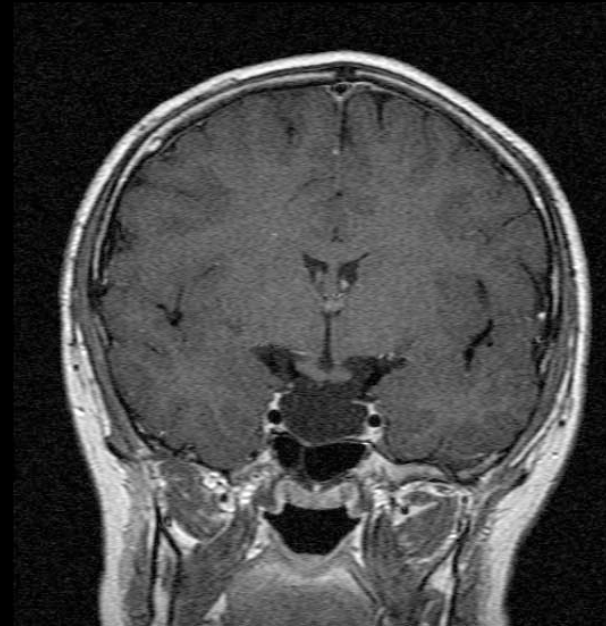
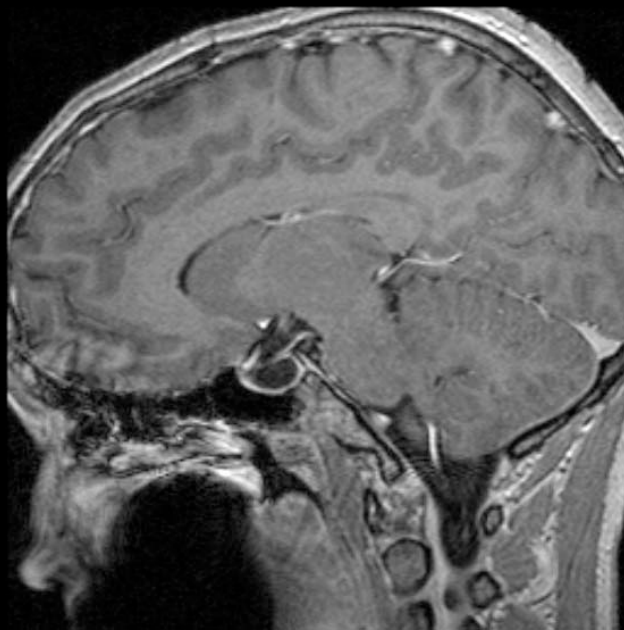
Pre-SRS Sep 2002



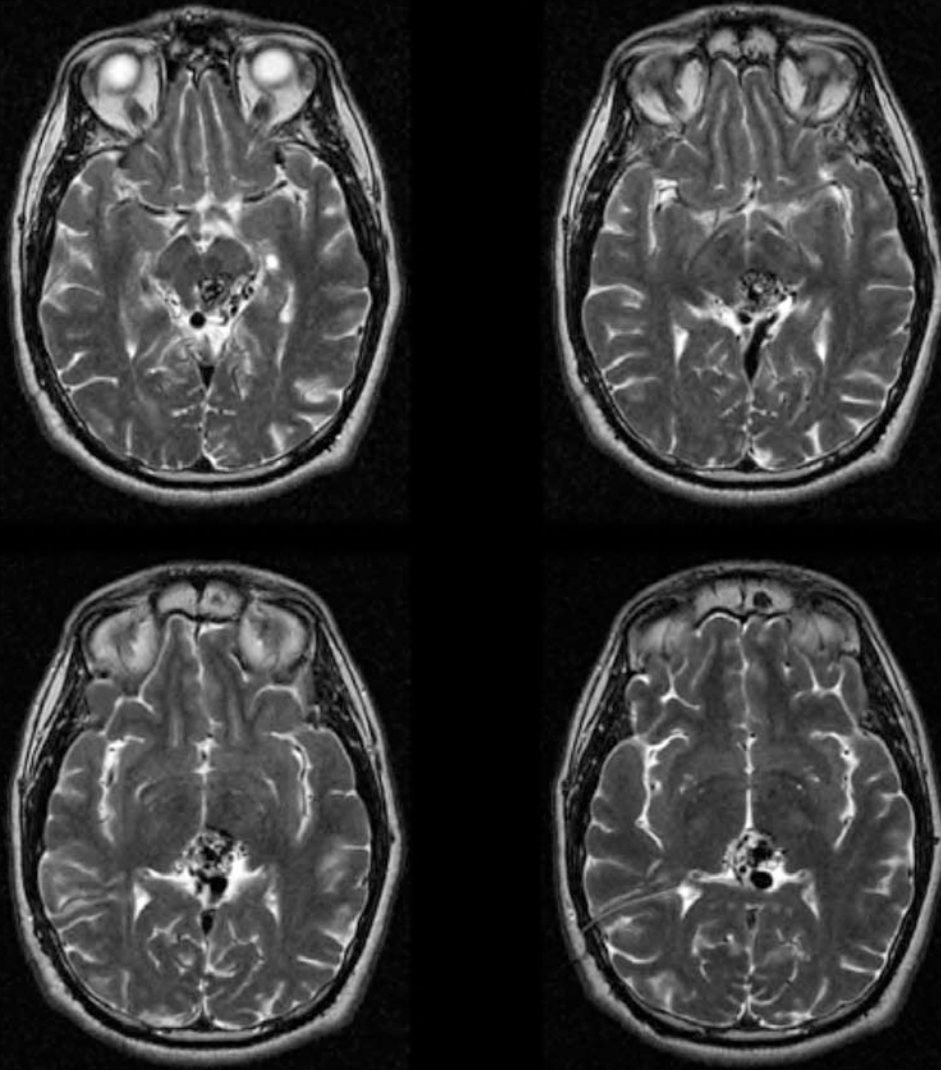
Case 1

14 yo male with craniopharyngioma

Post-SRS Jul 2003

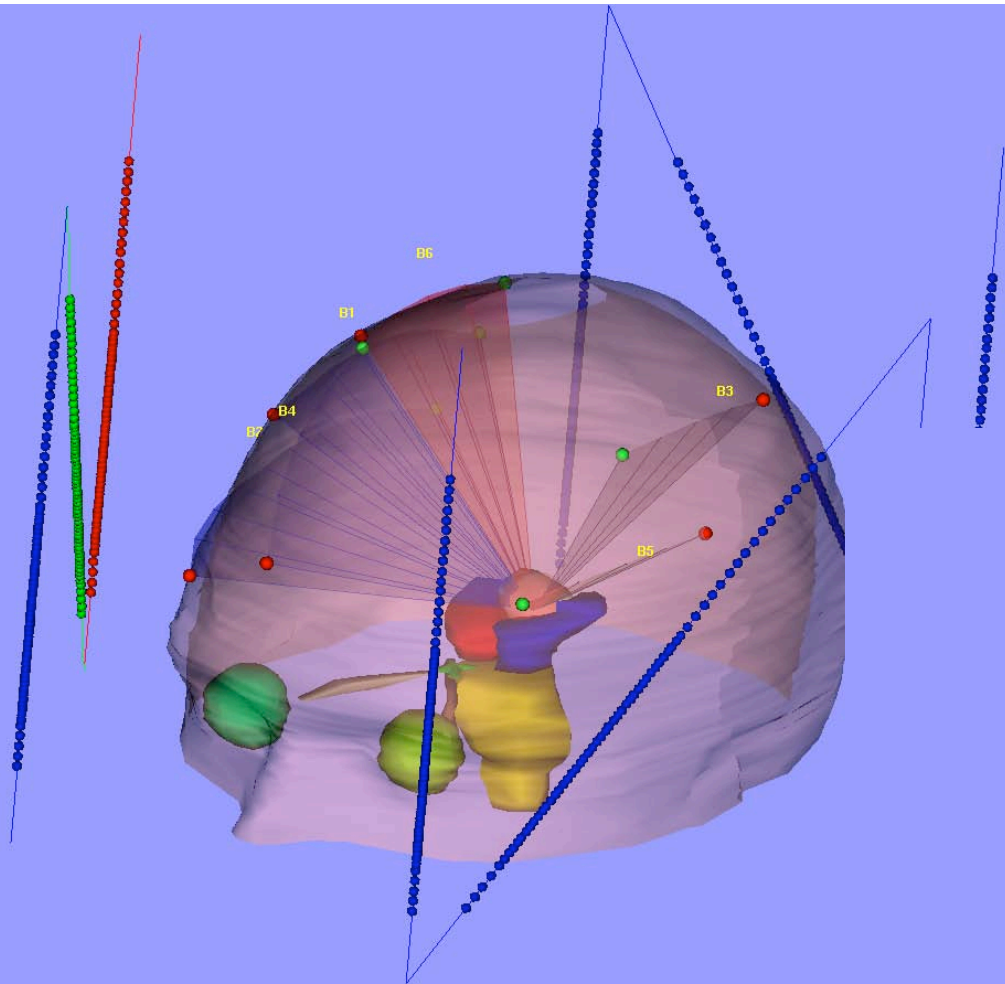


Case 2

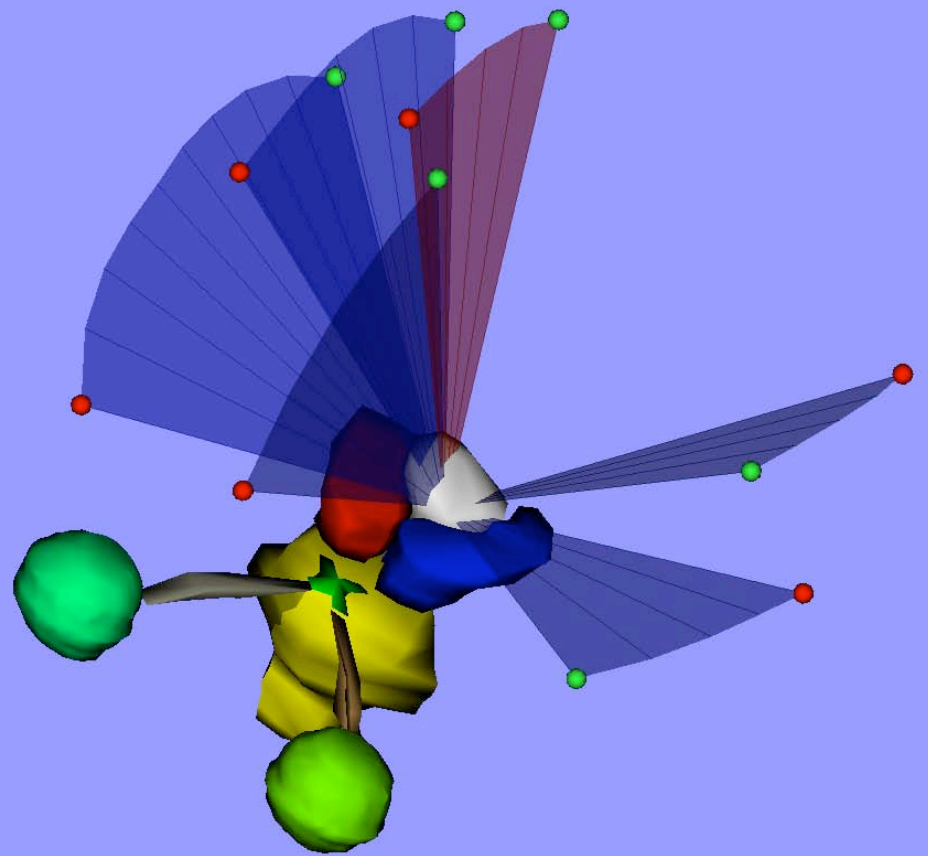


37 yo male with
AVM rupture,
Parinaud's syndrome,
hydrocephalus,
VP shunt

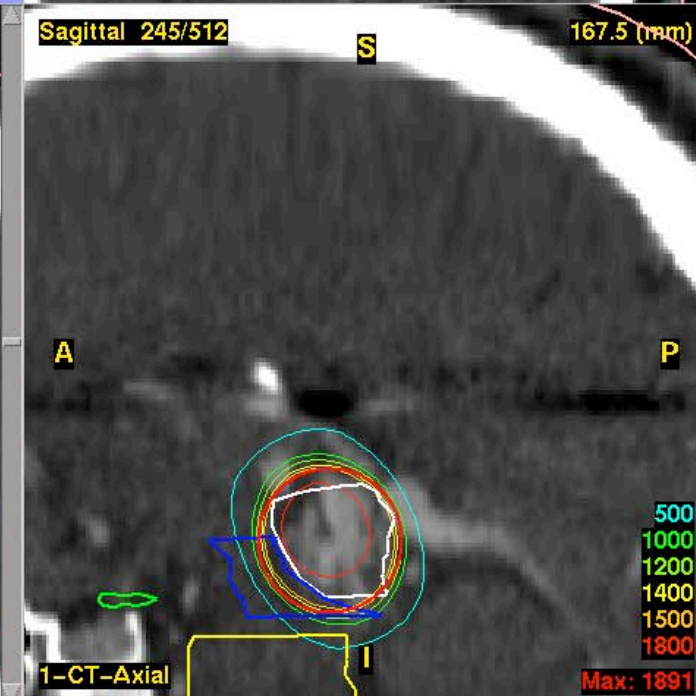
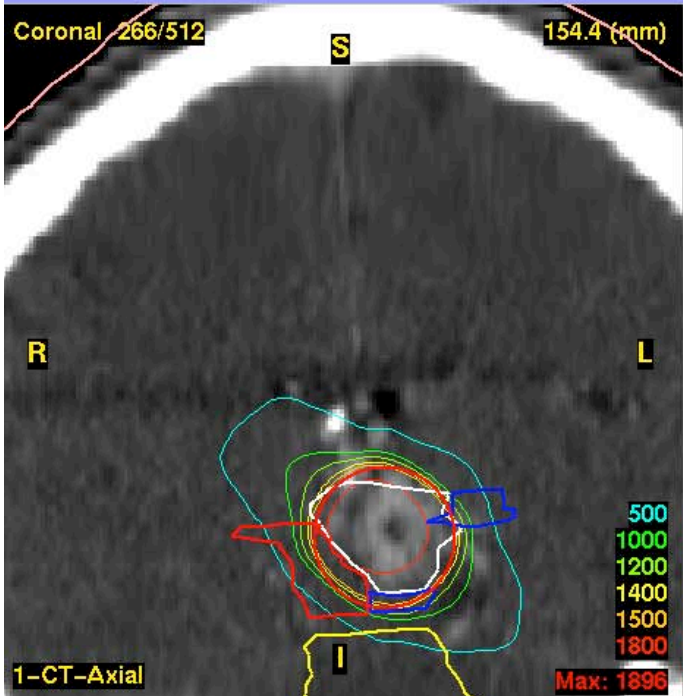
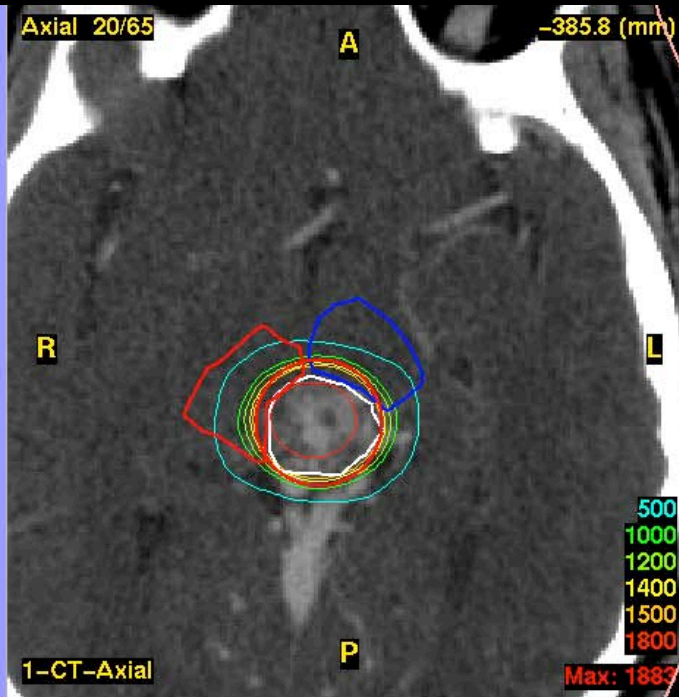
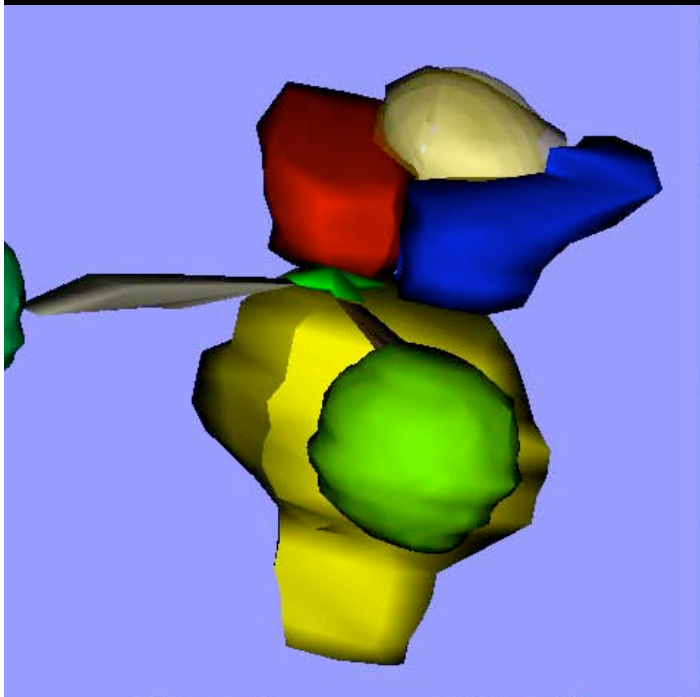
Case 2



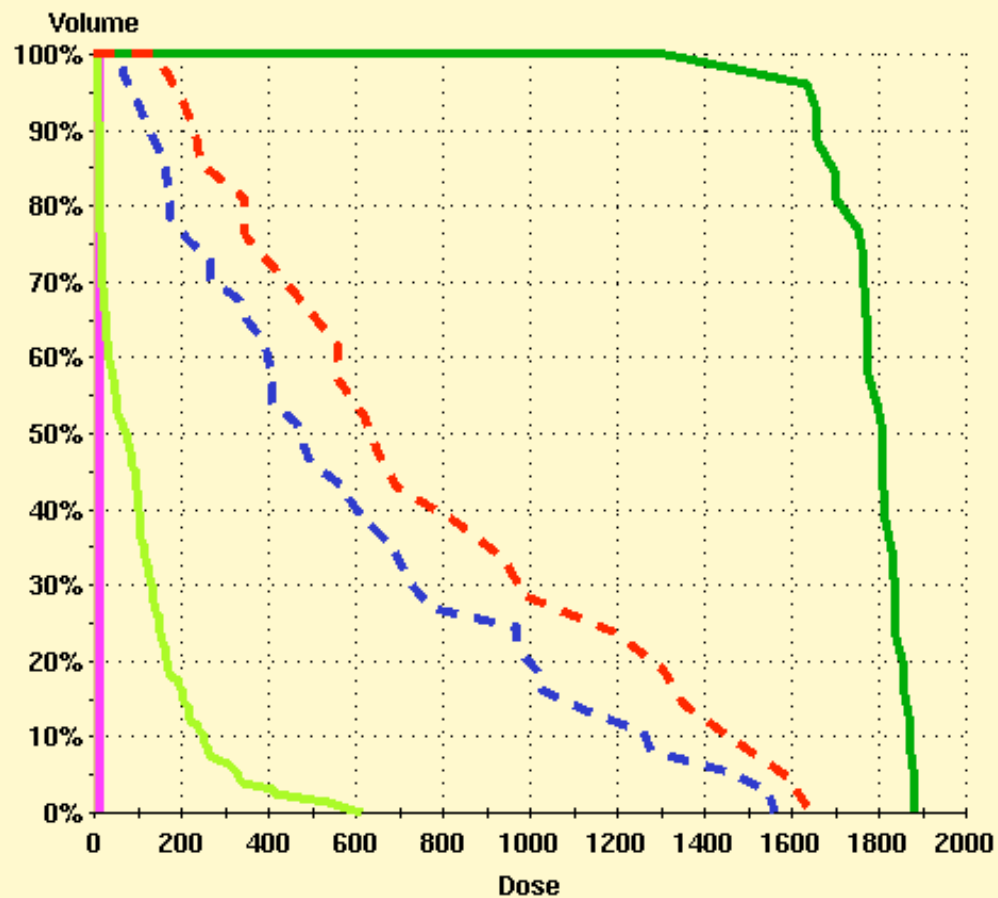
Midbrain AVM
SRS Oct 2002



Case 2



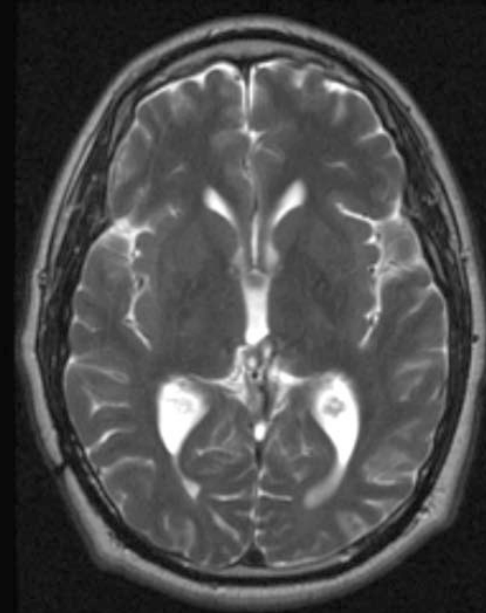
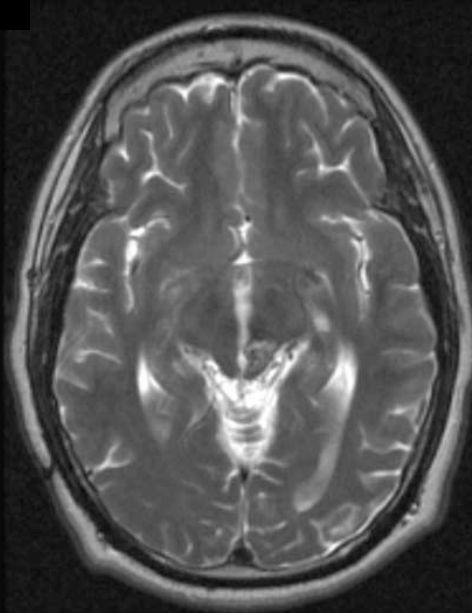
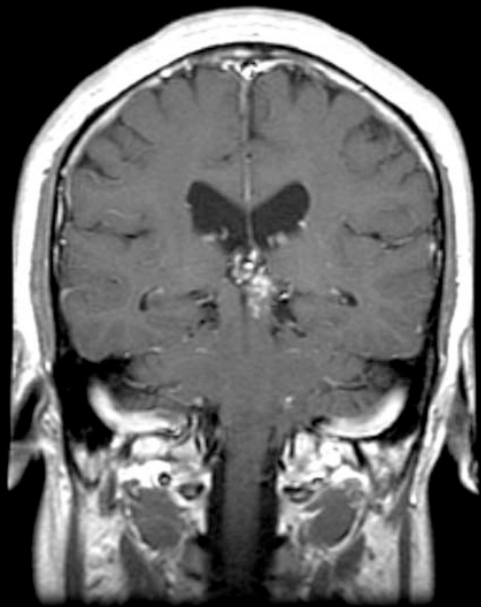
Case 2



- Anatome (volume, points)
- RightEye.1 (7.38 cc, 59)
 - LeftEye.1 (7.25 cc, 58)
 - PrimaryLesion.2 (3.25 cc, 26)
 - LeftOpticNerve.2 (0.00 cc, 0)
 - RightOpticNerve.2 (0.50 cc, 4)
 - OpticChiasm.2 (0.12 cc, 1)
 - BrainStem.2 (19.50 cc, 156)
 - R_midrain.2 (4.62 cc, 37)
 - L_midbrain.2 (2.62 cc, 21)

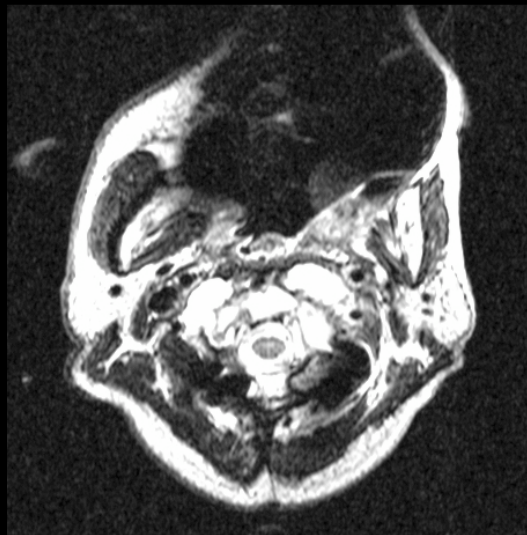
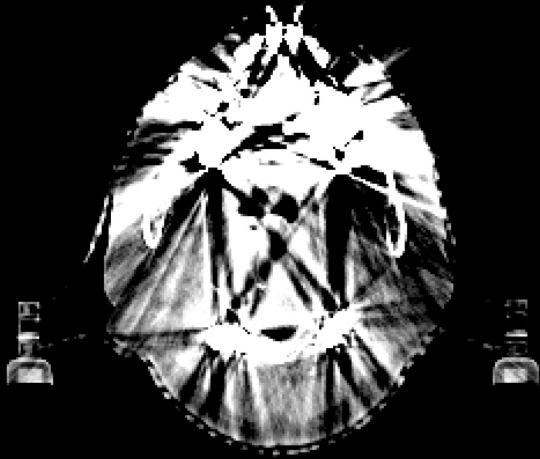
Case 2

Midbrain AVM
Sep 2004

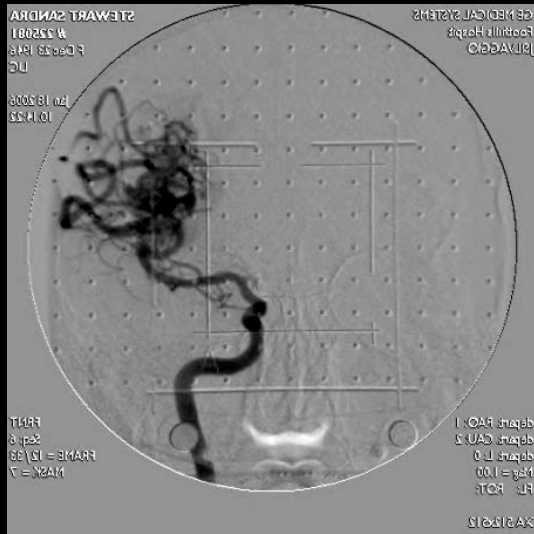




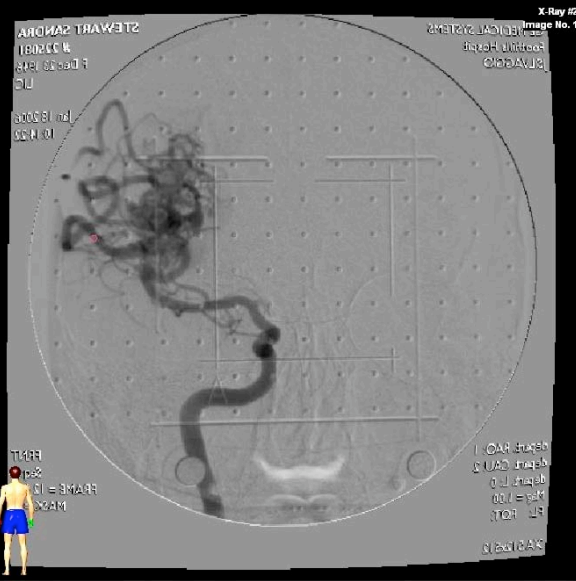
Challenges: Image distortion



Challenges: Image distortion

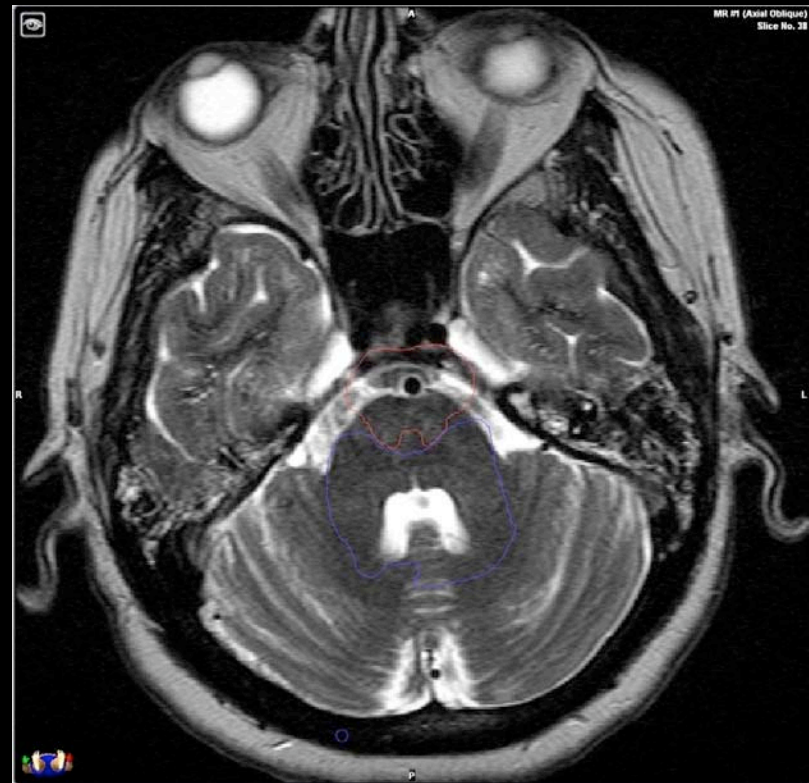
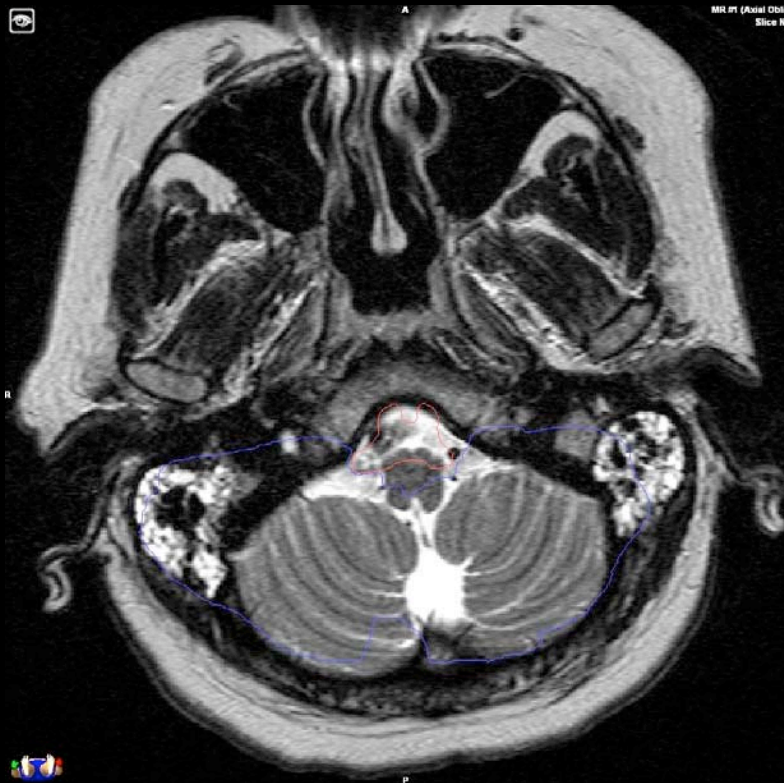


Original
angiogram



Corrected
angiogram

Challenges: Automatic segmentation



Challenges: Body Fixation

