Stereotactic surgery and frameless stereotaxy

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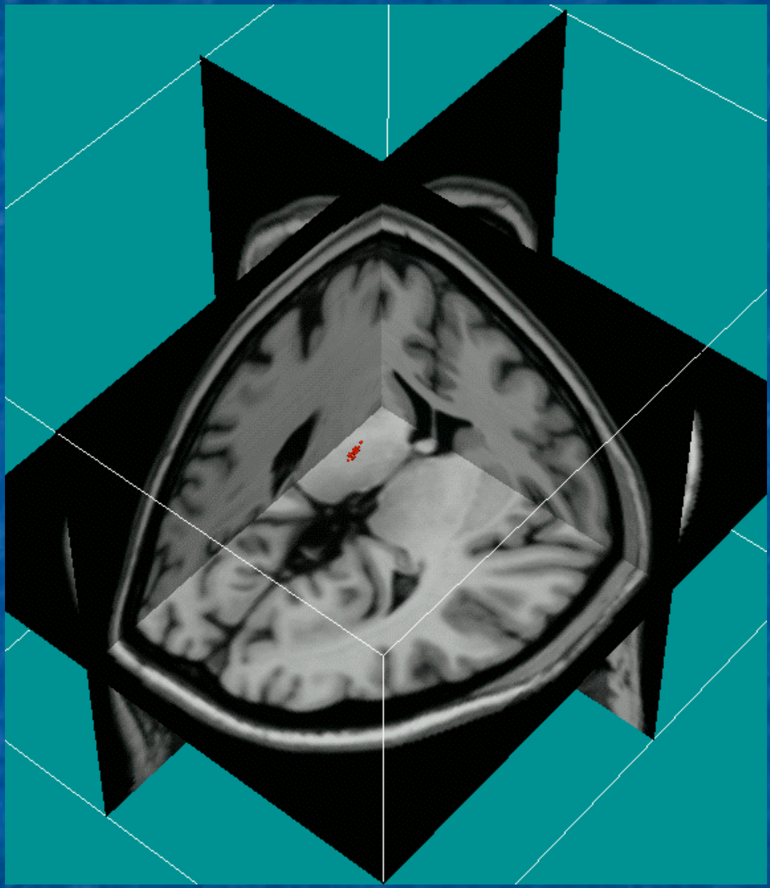
- Concept
  - The term "stereotactic" was coined from Greek and Latin roots meaning "touch in space”
  - A colorful term for this surgery is “neuro-navigation”
  - Use images of the brain to guide the surgeon to a target within the brain by utilizing the stereotactic principle of co-registration of the patient with an imaging study
    - This allows brain surgery to be accomplished with increased safety and smaller incisions by providing precise surgical guidance of the location of intracranial pathology.
  - This technique may utilize an external frame attached to the head (frame-based) or by imaging fixed landmarks or markers attached to the scalp (frameless or image guided surgery).

- Concept
  - The brain is considered as a geometric volume which can be divided by three imaginary intersecting spatial planes, orthogonal to each other (horizontal, frontal and sagittal) based on the Cartesian coordinate system. Any point within the brain can be specified by measuring its distance along these three intersecting planes.
    - X coordinate: distance to the midsaggital plane (right to left).
    - Y coordinate: distance along the rostrocaudal axis (anterior to posterior).
    - Z coordinate: distance in the coronal plane (superior to inferior).



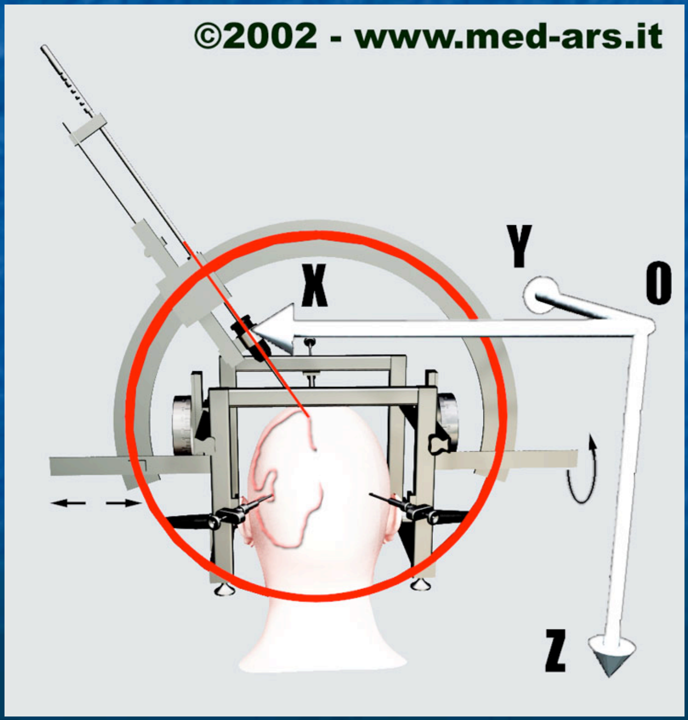
- General uses
  - Facilitates a precise planning of the craniotomy especially in cases of limited surgical exposure.
  - Facilitates a precise planning of the surgical vector to targeted small, subcortical lesions
    - Minimizes invasiveness by more accurately selecting the best trajectory to the lesion
    - Stereotactic biopsy of intracranial lesions.
  - Ensures more precise identification of normal structures for greater safety.
  - Helps to define the tumor margins and the limits of resection thereby guiding the complete removal of a lesion.
  - Useful in localizing encased and displaced vascular structures, the tumor extension into various brain crevices and the position of osseous landmarks.

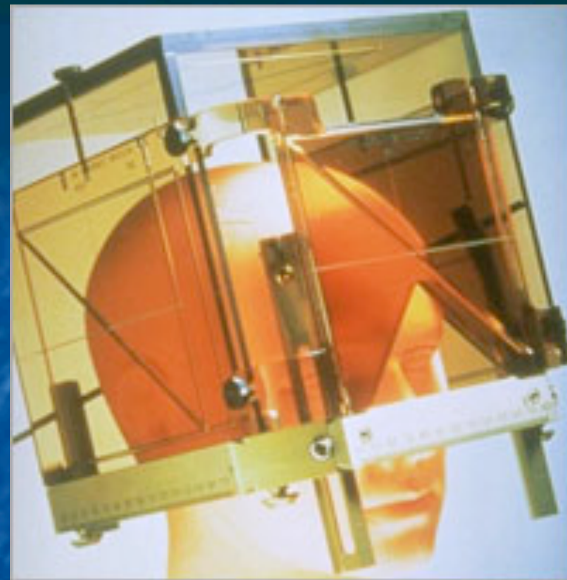
- General uses
  - Useful in predicting the length of the corpus callosum division in corpus callosectomy
  - Useful in judging the posterior margin of the anterior temporal resection and in localizing the hippocampus
  - An orientation within the ventricular system is provided in endoscopic surgery
  - The integration of functional imaging modalities, in particular, the magnetoencephalography (MEG), functional magnetic resonance imaging (fMRI) and positron emission tomography (PET) with neuronavigation has permitted surgery in the vicinity of eloquent brain areas with minimum morbidity.
  - The spatial accuracy of the modern neuronavigation system is further enhanced by the use of intraoperative MRI that provides real-time images to document the residual lesion and to assess for brain shift during surgery.

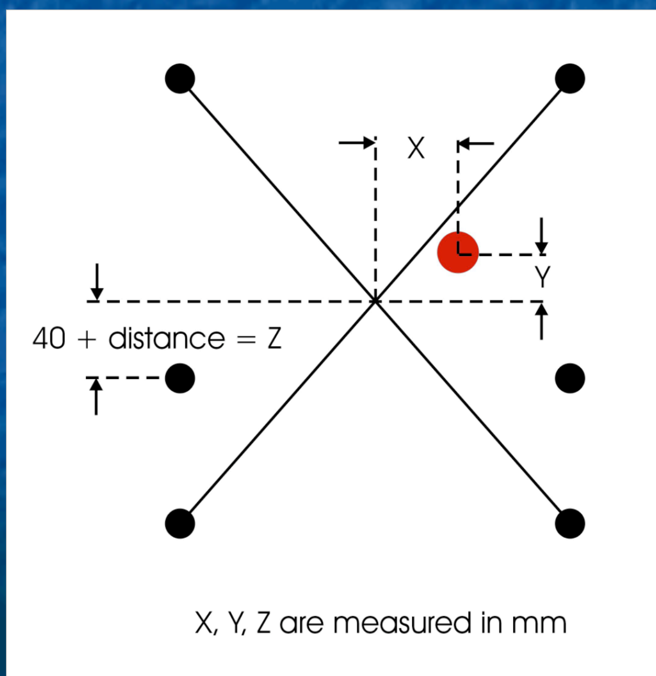
- Frame-based stereotactic surgery
  - A light-weight frame is attached to the head using local anesthesia.
  - Since both the frame and the target are "seen" in the images, the distance of the target from reference points on the frame can be measured in three dimensions.
  - Surgical apparatus attached to the head frame can be adjusted to the three dimensional coordinates of the target and the target can be accurately approached by the surgeon.

- Frame-based stereotactic surgery
  - Spiegel and Wycis (1946): First stereotactic instrument used in human surgery. They used the foramen of Monro and the pineal gland as landmarks imaged with ventriculography. Used for coagulation of the dorsal median nucleus of the thalamus.

- Modern frame
  - Lars Leksell (1949): the arc-quadrant. The target is the centre of the arc.
  - Burr Hole-Mounted Systems.
- Modern imaging
  - The head is imaged by CT, MR or angiography to identify the target in relationship to the external frame.



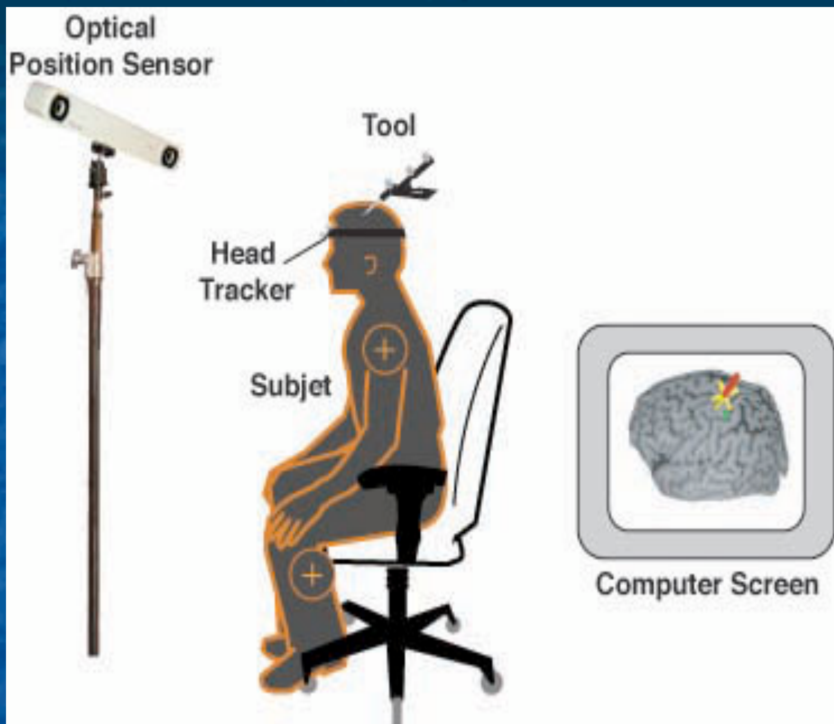


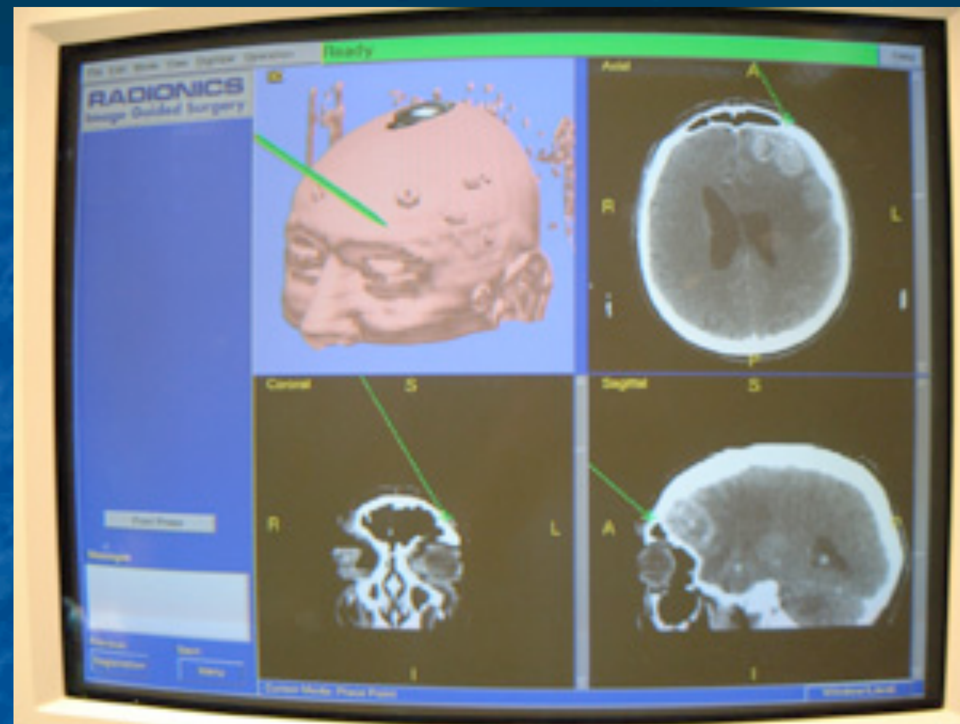

X
Y
40 + distance = Z
X, Y, Z are measured in mm

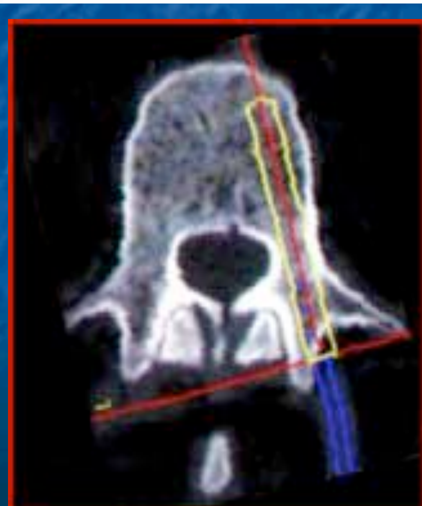
- Common uses
  - Stereotactic brain biopsy. Deep tumors within the brain may be difficult and dangerous to approach by an open operation. Using a stereotactic biopsy apparatus fixed to the head frame and adjusted to the target coordinates, a biopsy probe is passed through a small hole in the skull to sample tissue for pathology.
  - Placement of lesioning electrode for pallidotomies, thalamotomies etc.
  - Placement chronic stimulation electrodes in the deep brain to treat movement disorders, such as Parkinson’s disease and essential tremor.
  - Can make functional maps of subcortical structures using recording electrodes
  - Cell transplantation
  - Stereotactic braquitherapy
  - Shunt catheter placement
  - Stereotactic radiosurgery

- ***Frameless stereotactic surgery***
  - Based on the principle of the global positioning system.
  - Relies on anatomical landmarks on the patient's head and/or fiducial markers (temporary skin markers) which are taped to the scalp before the brain is imaged.
  - In the operating room the orientation of these markers is used to register the computer containing the brain images.
  - References this coordinate system with a parallel coordinate system of the three-dimensional image data of the patient that is displayed on the console of a computer-workstation so that the medical images become point-to-point maps of the corresponding actual locations within the brain.
  - Common uses
    - Very helpful for the accurate approach and removal of large brain tumors.
    - Provide the surgeon with navigational information, relating the location of instruments in the operative field to preoperative imaging data. A digitizing camera senses the position of the surgeon's instruments in space and indicates the position of the instrument on the image displayed on the computer monitor in real time, as the operation proceeds.
    - The surgeon can also navigate through the brain using the computer images linked to a microscope.
    - Useful in minimally invasive spinal neurosurgery such as the placement of instrumentation to stabilize the lumbar spine.

- Procedure
  - Skin fiducial markers (usually 6) are attached to the patient's head
  - MRI performed
  - Data transfered to surgical navigation computer workstation.
  - The determination of a specific point in the image space of this workstation that corresponds to its actual location during surgery requires registration of the system to the fiducials on the patient
  - Consists of a mounted array of cameras, a computer workstation with a high resolution monitor, a dynamic reference frame attached to the Mayfield head holder and a free handheld stereotactic pointing device.
  - Performed at surgery, once the patient's head is fixed to the Mayfield head holder, the process of registration is carried out by pointing the hand-held stereotactic pointing device at each fiducial marker. The skin markers are registered using a probe that is linked to the computer by a camera which detects the probe's position in space. This marries the position of the head in space with the images in the computer. This patient-to-image registration can be achieved either by correlating fiducials on the skin or bone or by matching external rigid landmarks.
  - The navigation accuracy is ascertained by inspection of anatomical landmarks.


Optical
Position Sensor
Tool
Head
Tracker
Subjet
Computer Screen


Ready
RADIONICS



- Accuracy of frameless navigation
  - Zinreich et al, defined the limits of the best accuracy (an average of 1-2mm) that can be expected in vivo, by testing the viewing wand system on a plastic model of the skull.
  - Golfinos et al, achieved an accuracy of 2mm in 82% of their patients using CT images and 92% using MR images and felt that the more accurate registration with MR than CT was because of greater familiarity with MRI reconstruction in multiple planes.
- The accuracy of the system is compromised by many factors.
  - The slice thickness of the scanned image determines its voxel resolution and therefore its accuracy of registration. Interpolation of voxel intensities during reformatting of images further enhances the registration error.
  - Patient motion
  - Artifacts in the CT or MR scans
  - Change of position of the fiducials or shifting of the skin
  - Faulty placement of probe on the exact location of CT and MR images
  - As the actual surgical position is related to the images acquired preoperatively, a progressive error in registration is observed during intraoperative navigation due to the brain shift which depends on the patient position, brain edema, bleeding, cerebrospinal fluid volume change, tumor removal, cerebral blood volume, use of mechanical ventilators or diuretics or retraction during surgery.
    - Dorward et al, quantified brain shifts during open cranial surgery to assess the impact of postimaging brain distortion on neuronavigation and reported a mean shift of 4.6mm of the cortical surface after the dural opening and 6.7 mm at completion of tumor resection. The shift at the deep tumor margins in cases of convexity meningiomas was significantly more than gliomas while skull base lesions demonstrated little brain shift.