Stereotactic Neurosurgery

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STEREOTACTIC NEUROSURGERY - use of coordinate system to provide accurate navigation to point / region in space (e.g. deep brain structures) without direct visualization.

Indications for stereotactic procedures:

1. Biopsies of ***structural lesions***.
2. Treatment of ***functional abnormalities*** (movement disorders, pain conditions) – by lesioning or brain stimulation.
3. Stereotactic ***implantations*** of neural tissue, drug transplants, gene therapy.

Now stereotaxis is IMAGE-GUIDED (i.e. directly visualizing target with CT / MRI);
prior to introduction of CT / MRI, target localization involved injecting ***air*** or ***positive contrast*** into lateral ventricle to outline third ventricular structures adjacent to diencephalic targets

FRAME-BASED STEREOTAXIS

- uses stereotactic frame rigidly attached to skull.

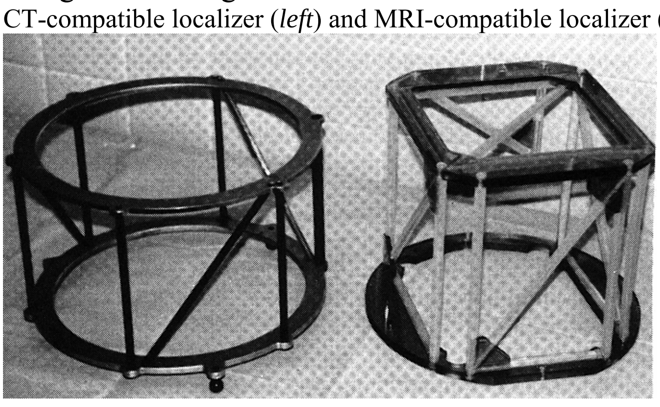
- most commonly used stereotactic frames:
  1) Brown-Roberts-Wells
  2) Cosman-Roberts-Wells
  3) Leksell Model G
- frame is applied directly to skull (under local anesthesia) by four threaded pins that penetrate only outer table of skull → LOCALIZING BOX is attached to frame → imaging to align brain, lesion, and stereotactic frame → TRAJECTORY PLANNING* → stereotactic arc is mounted on frame → biopsy.

**see below >>*

LOCALIZING BOX is most accurate method of localization; it is scanner-independent and computer-assisted;

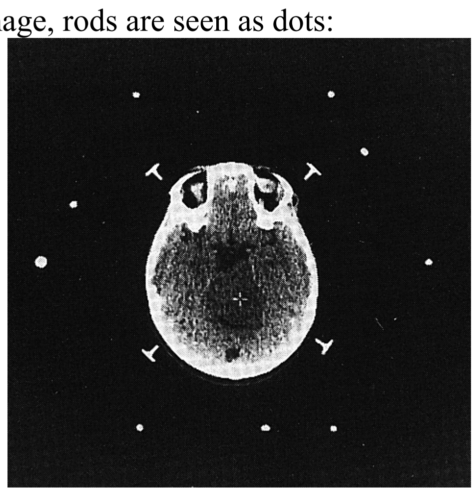
– localizing box with three sets of vertical and diagonal fiducial rods in N configuration is attached to base ring → scanning.

CT-compatible localizer (*left*) and MRI-compatible localizer (*right*):



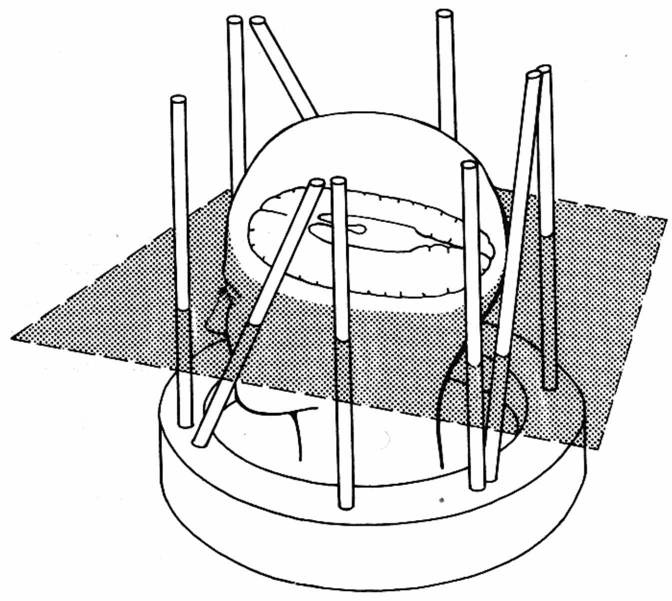
Source of picture: Marshall B. Allen, Ross H. Miller "Essentials of Neurosurgery: a guide to clinical practice", 1995; McGraw-Hill, Inc.; ISBN-13: 978-0070011168 >>

– in resulting image, rods are seen as dots:



Source of picture: Marshall B. Allen, Ross H. Miller "Essentials of Neurosurgery: a guide to clinical practice", 1995; McGraw-Hill, Inc.; ISBN-13: 978-0070011168 >>

– *z* coordinate is obtained by determining position of each diagonal rod image in relation to its adjacent vertical rods; three such sets of vertical and diagonal rods determine three points in stereotactic space and define plane of target point:



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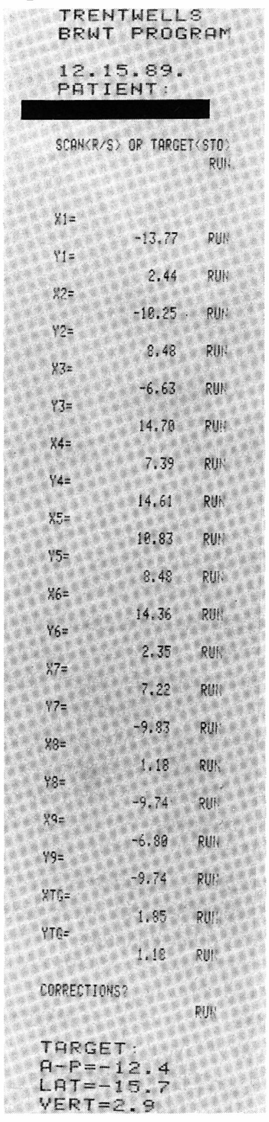
Thermal paper printout of x, y data for nine fiducial localizer rods and target. 3D target data are printed out at sheet bottom:



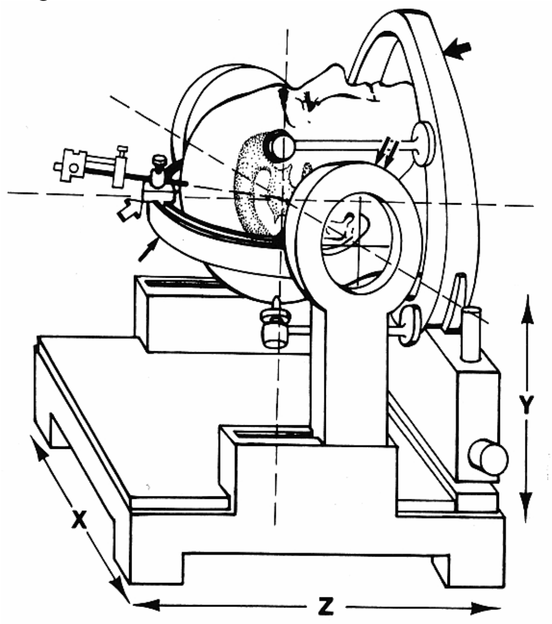
– *x*, *y* coordinates of each of nine rods are entered into computer, which calculates distance from each of three diagonal rods to base ring, based on proportionate distance of each diagonal rod from its associated vertical rods in that plane; these three points define target plane relative to base ring, and from this 3D coordinates of target are calculated.
N.B. coordinates are referable to stereotactic base ring.
– lateral (*x*) measurements are denoted "left -," "right +"; AP (*y*) measurements are denoted "anterior +" or "posterior -"; vertical (*z*) measurements are denoted "superior +" or "inferior -".
– because of variability of patient positioning in stereotactic instrument, isocenter of three orthogonal planes of stereotactic space will rarely superimpose upon intersection of corresponding intracranial planes as depicted in human stereotactic brain atlases.

STEREOTACTIC FRAME TYPES

TARGET-CENTERING ARC-RADIUS stereotactic instruments (Todd-Wells instrument, Kelly instrument)

- patient's head is fixed in base ring that is separate from but attached to same platform as aiming arc.
- arc rotates around horizontal axis, and probe holder may be moved to any position along arc.
- trunnions on which arc rotates and arc itself have angular calibrations so that any procedure can be performed using *entry-point* or *angles-of-entry* technique. see below >>
- focal point of arc remains fixed in 3-dimensional stereotactic space - it is patient's head (with its intracranial target) that is moved in any of three orthogonal planes to focal point of instrument.
- Vernier scales calibrated in millimeters allow accurate measurement of head movement in each of three planes (radius of the arc system as well as its focal point remain fixed - therefore, target distance from arc is always known, regardless of where twist drill hole entry point is placed).

TODD-WELLS stereotactic instrument - skull is fixated in base ring (*large white arrow*) which can be moved along any of three rectilinear directions; arc (*small white arrow*) can rotate on trunnions (*large black arrow*), but its base (marked with *vertical white labels*) does not move; guide block (*small black arrow*), through which probe passes, can be moved to any point along arc:



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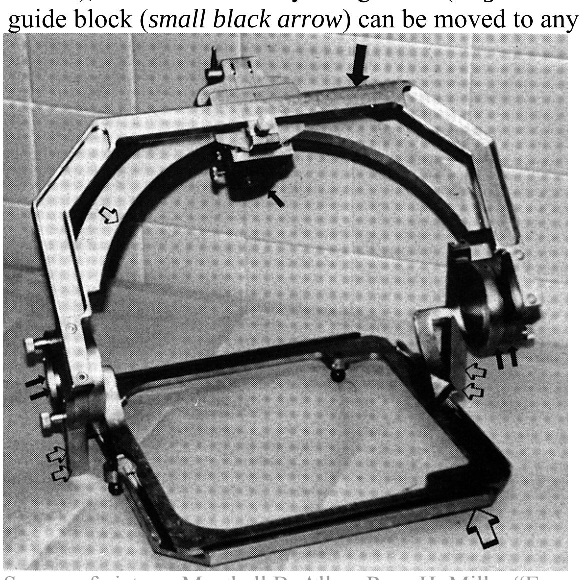
ARC-CENTERING ARC-RADIUS stereotactic instruments (Cosman-Roberts-Wells [CRW] instrument, Leksell apparatus)

- arc, which is fixed to base ring on patient's head, is moved in order to bring its focal point to target.
- *entry point* or *angles-of-entry* technique may be used. see below >>

COSMAN-ROBERTS-WELLS [CRW] instrument - base plate (*large white arrow*) attaches to base ring; arc (*small white arrow*) can be moved in AP direction along grooves in base plate and superior-inferior along vertical bars (*small double white arrows*); arc moves laterally along U bar (*large black arrow*), which is attached to trunnions; arc rotates on trunnions; guide block (*small black arrow*) can be moved to any position along arc:



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ROBOTICS

- replacing aiming device or arc system with robotic arm.

- instead of transferring 3D stereotactic target coordinates to arc system, computer calculates these coordinates and transfers them to robotic arm.
- special computer software is used to translate target and entry-point data into angular settings for each of moving joints of robotic arm, and it also programs depth of probe penetration.
- each of joints of robotic arm contains *servomotor*; servomotor houses optical incremental encoder, which provides position and velocity feedback to robot servosystem - position of probe tip can be displayed relative to lesion on operating room computer monitor in real time.
- robotic arm is mounted to stereotactic base ring (fixed to patient's head - serves as reference base plane for system, as in standard stereotactic systems).
- custom-designed probe holder is attached to robotic arm and allows for intraoperative fine adjustment of probe position.

FRAMELESS STEREOTAXIS

- rendering of scans (CT / MRI) into 3D images → rendered view of patient is aligned with actual patient using 3D digitizer, once patient is fixed in constant orientation in operating room.

- digitization can be performed using either ***fiducial marks*** (skin staples, pins attached to skull) or ***scalp surface*** - computer aligns actual patient (as digitized) with computer representation obtained from radiologic images.
- digitization can be performed by:
  a) mechanical device (such as sensor arm similar to that used in robotics)
  b) line-of-sight device (such as video camera or sound waves).
- ***brain warping*** may occur (e.g. following opening of skull, CSF leakage, partial tumor excision) → affected accuracy of device; H: brain updating (such as 3D ultrasound).

  N.B. without rigidly attached frame, surgeon no longer has to deal with physical obstruction from frame (e.g. turning craniotomy flap), but there may be *sacrifice in accuracy* - biopsy of **small tumors**, lesions for **movement disorder** still require stability and accuracy of frame!

STRUCTURAL STEREOTACTIC PROCEDURES

- for structural lesions that can be detected on imaging study (tumors, abscesses, infections)

1. **Biopsy** (avoid vascular malformations and strokes!)
2. **Stereotactically guided endoscopic / open craniotomies** - removal / debulking of deep-seated lesions with minimal manipulation of overlying tissue
3. **Stereotactically guided** intracerebral hematoma / abscess **evacuation** (esp. deep-seated and multiple).
4. **Interstitial / intracavitary irradiation** see p. Rx11 >>

5. **Radiosurgery** (application of stereotactic principles to convergent beam-ionizing irradiation therapy) – noninvasive!!! see p. Rx11 >>

FUNCTIONAL STEREOTACTIC PROCEDURES

- changes function by altering aspect of abnormal functioning circuit (which may be upstream or downstream from pathologically affected part of circuit).

- indications: movement disorders, pain, epilepsy.
- target is usually anatomically defined and requires *precise localization by brain atlases*, in coordination with patient's own anatomy.

Destructive methods:

a) radiofrequency heat lesions - easiest to grade (temperature control of electrode tip); temporary lesions can also be produced prior to causing permanent damage to brain
b) mechanical lesions (with small wire loop)
c) freeze lesions (cryolesions using liquid N_2)
d) balloon lesions (to percuss surrounding brain on inflation)
e) chemical lesions.

Augmentative methods – chronic brain stimulation, cell or tissue transplants, gene transfer.

TRAJECTORY PLANNING

- safe trajectory avoids *major cortical vessels* and areas of *functional cortex*.
- safe ENTRY POINT - within watershed zone between ACA and MCA (or PCA and MCA); this zone is usually centered ≈ 3 cm off midline; most frequently, level of coronal suture (or point 1-2 cm anterior to it) is chosen - paucity of draining veins in this area.
- risk of hemorrhage is decreased by studying preoperative ***angiograms*** and minimized by preoperative ***stereoangiography***.

  e.g. CT or MRI localizer is replaced with angiographic localizer → digital subtraction angiography → selected views are transferred to computer → computer derives stereotactic coordinates of avascular cortical entry point.
- trajectory (probe tract) goes through white matter - blunt probe tip pushes axons aside (rather than transecting them).
- **burr holes** or **larger openings** allow CSF escape + air entry → shift of intracranial structures → suboptimal probe placement; H: use **small twist drill hole** instead.

Trajectory planning is accomplished in either of two ways:

A) ***ENTRY POINT TECHNIQUE*** - choosing entry point on scalp; target and entry points define straight trajectory.

B) ***ENTRY ANGLES TECHNIQUE*** (particularly useful when operating on superficial lesions*) - best accomplished with *computer-generated graphic simulation* (if initial angles of trajectory appear unfavorable, computer may be used to modify them, and new angles can then be transferred to stereotactic device); can be utilized with:

a) ***arc-radius system*** - type of instrument, AP and lateral angles are used to construct trajectory.
b) ***polar coordinate system*** - some use AP and lateral entry angles; others use horizontal (azimuth) and vertical (declination) angles of entry.

*even slight misplacing of entry point may make trajectory almost tangential to skull (twist drill will need enlarging in order for probe to pass to target).

Confirmation of *CORRECT PROBE PLACEMENT* is essential:

a) ***radiographically*** (fluoroscopy or roentgenograms)
b) ***physiologically*** (stimulation or recording).

- it is always wise to archive final probe position (not only in operative notes but also with X-rays, computer printouts, or on magnetic tape).

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