Robotics in Brain Neurosurgery

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What's is the modern Robot?

A robot is defined, according to the Robotic Industries Association as a "reprogrammable, multifunctional manipulator designed to move materials, parts. tools, or specialized devices through variable programmed motions to perform a variety of tasks"

Medical Robotics Advantages

The field of medical robotics offers a number of attractive features. The specific objectives of this technology include:

- Improve accuracy of procedure.
- Allow finer control.
- Increase reproducibility (consistency).
- Incorporate complicated, detailed and voluminous image data in surgical execution.

Medical Robotics Advantages (cont.)

- Allow remote activation which could expand access to operator expertise for patients.
- Allow longer endurance than humans in the same task.
- Improve safety - a robot can safely intervene in situations where infection risk to a human operator may be high.
- Minimize invasion of procedure.
- Provide new possibilities for miniaturization of the surgical task.

History Robotics in Brain Neurosurgery

- 1985 Kwoh et al performed first robot assisted CT guided brain biopsy with PUMA an industrial robot
- Prof Alim Benabid at Grenoble University, France develop original Neuromate
- 2000 Neuromate first neurosurgical robot certified by the US FDA

  (Li, Zamorano, et al Comput Aided Surg 2002;7 (2):90-98)
- 2000 First CT/MRI guided biopsy with Neuromate in the United States (L Zamorano, Detroit, MI)

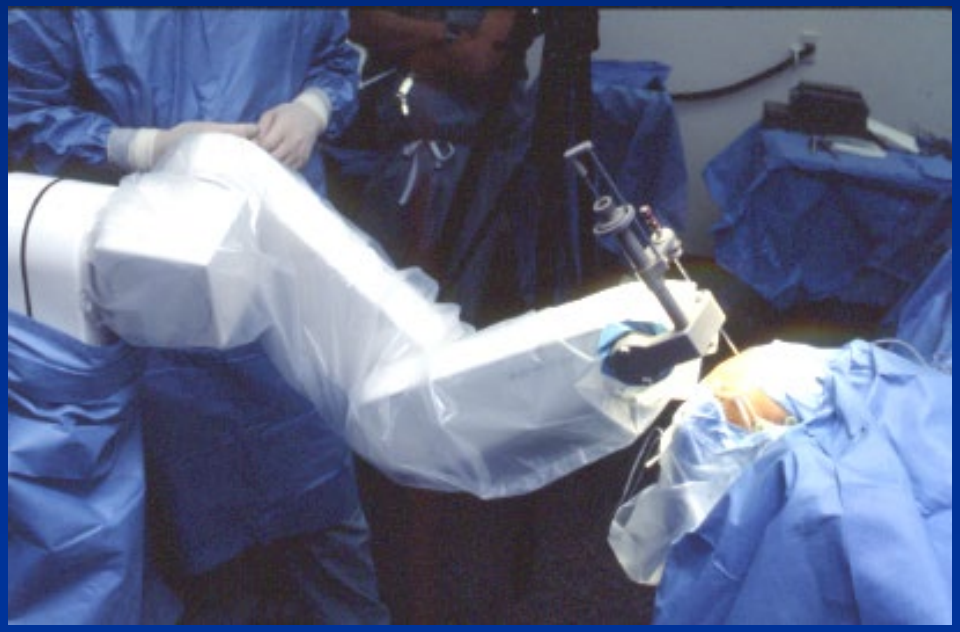
  (Zamorano L, et al Intern J. medical robotics and CAS 2004 1 (1):7-22)
- Neuromate still in use (Renishaw, UK)

Clinical Applications of Robotics in Brain Neurosurgery

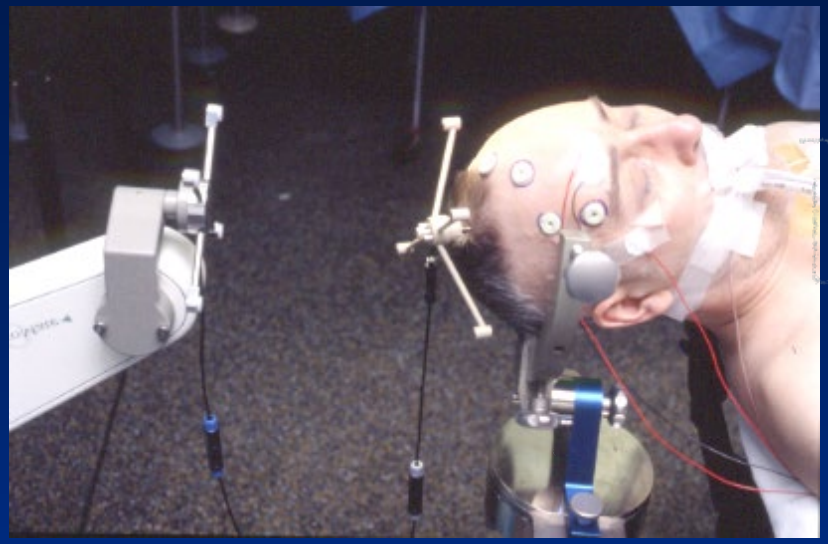
- Functional neurosurgery: SSEG, DBS
- Biopsy
- Assist Resection of intracranial lesions
- Radiofrequency Thermocoagulation
- Laser Interstitial Thermal Therapy
- Neuroendoscopy
- Drug delivery (convection-enhanced drug delivery (CED))
- Radiosurgery
- Laser Osteotomy

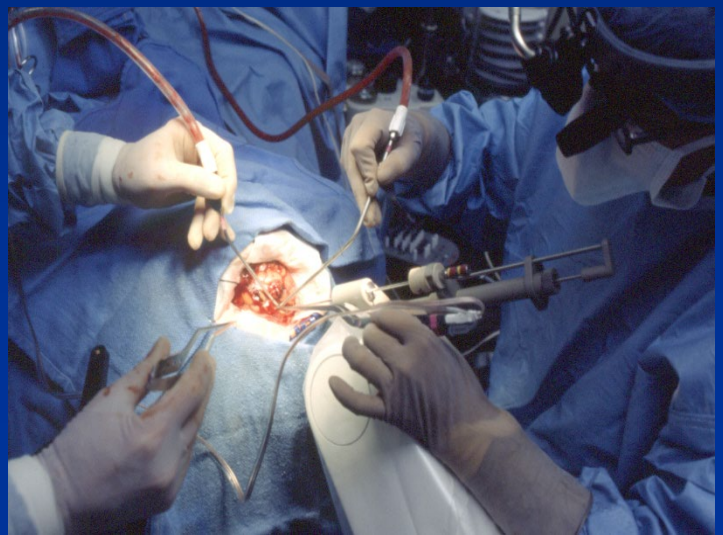
NeuroMate:Robot

- NeuroMate(TM) System ISS (Integrated Surgical Systems, Davis, CA).Lately Renishaw, Wooton-under-Edge, UK
- NeuroMate is 5DOF robot and allows both frame and frameless approaches.



Intraoperative Robotic Use for biosy and resection of tumor



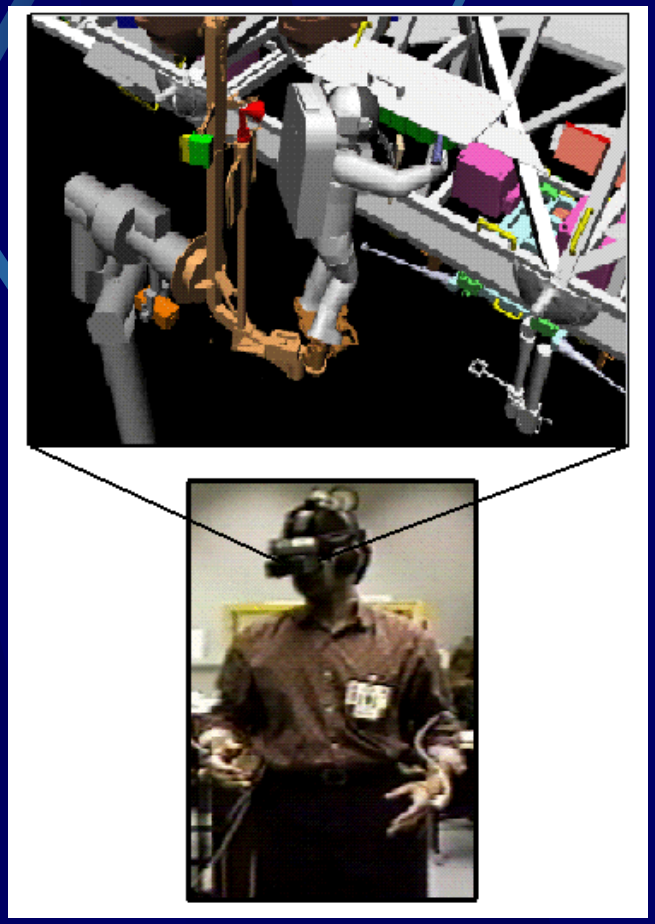


Augmented Reality Visualization

(CAS Lab WSU, Detroit,MI)

* **Virtual Reality (VR):** A synthetically generated world (e.g. 3D segmentation models) that is presented to the user. The real world is occluded from the user.

* **Augmented Reality (AR):** A real view of the environment (the patient) merged with a synthetically generated world. The real world and virtual world objects are presented together on a single display device.



*Clinical Experience with Neuromate Robot (1999-2002) **

- 43 patients
- Type of surgical procedures :
  - 23 craniotomies for tumor resection.
  - 5 stereotactic ventriculoperitoneal shunts placement.
  - 2 craniotomy for epilepsy
  - 8 radioactive I-^{125} implant placement.
  - 5 case of stereotactic biopsy.

*Harper University Hospital, Detroit, MI

Clinical Experience with Neuromate Robot (1999-2002)
Results

- No complications were reported associated with its application.
- Efficient (very fast) intra-operative registration .
- High degree of accuracy.
- Optimal and accurate placement of various tools i.e. needle biopsy, catheters, electrodes.
- Accurate positioning of craniotomy
- Robotic base position obtrusive in some patients position
- Laser beam as a pointer attached to robot very useful for image guidance at different times of surgical procedure: skin incision, craniotomy/ burrhole, lesion margins.
- Augmented Reality improves intraoperative guidance

*Harper University Hospital, Detroit, MI

Clinical Experience with Neuromate Robot (1999-2002) Conclusions

- Accurate
- Efficient intraoperative registration
- Optimal placement of linear tools
- Useful to define craniotomy site and margin of lesions although cumbersome
- It needs integration with interactive system for feedback of position of surgical tools during open procedures
- It needs flexibility of robot base position

*Harper University Hospital, Detroit, MI

Robotic Operating Microscope

- “true” navigation and guidance
- image projection(heads-up display)
- integration with microscope’s optical system

Robotic Operating Microscope

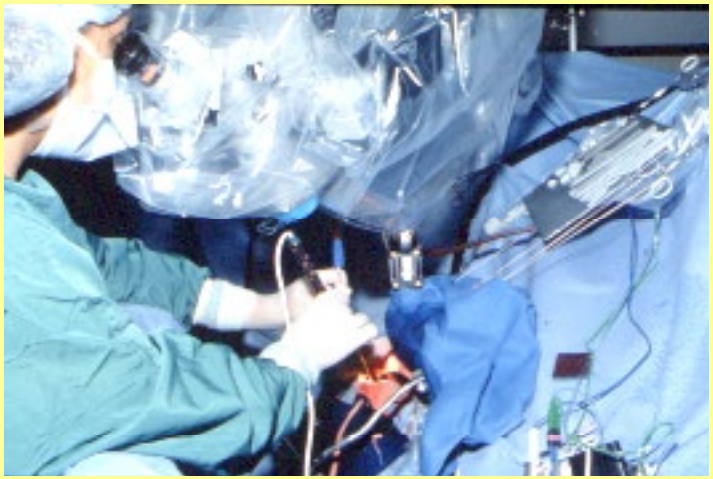
Surgical Planning

- Image registration
- Target and other “volumes of interests” definition
- Trajectory definition

Robotic Operating Microscope
Intraoperative Registration

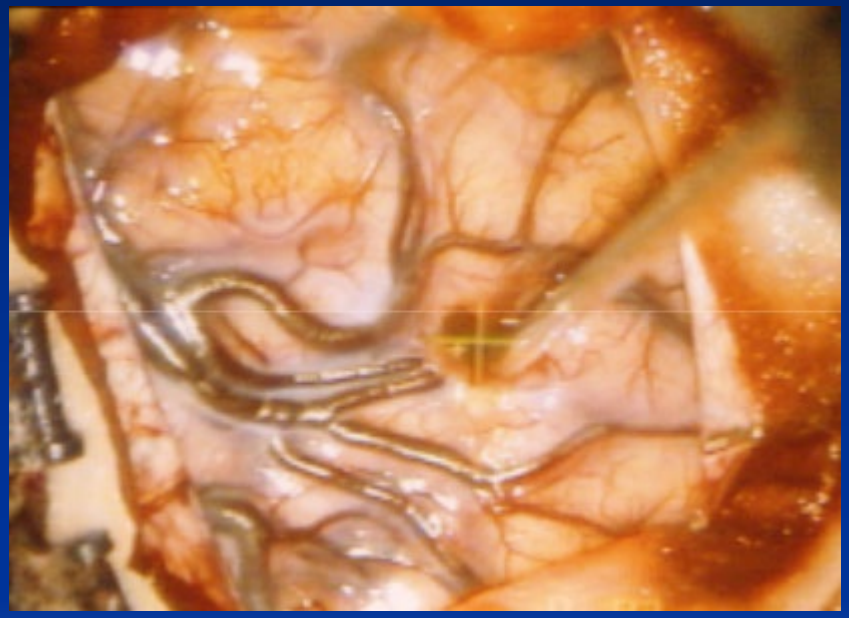
- Image-space registration
- focal distance and autofocus at maximal magnification

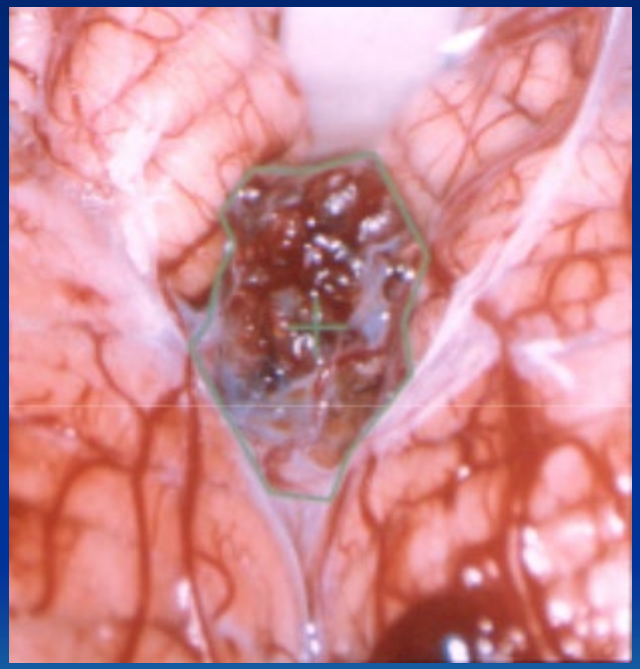
Robotic Operating Microscope



Using MKM and infrared tracking system during surgery.

Robotic Operating Microscope : intraoperative heads-up display





Robotic Operating Microscope
Intraoperative Guidance and Navigation

- “true” navigation (R)
- remote control of microscope position (R)
- display of contours from surgeon’s perspective(D)
- continues display of center of focal point (D)
- Intuitive, fast and reliable

Robotic Operating Microscope

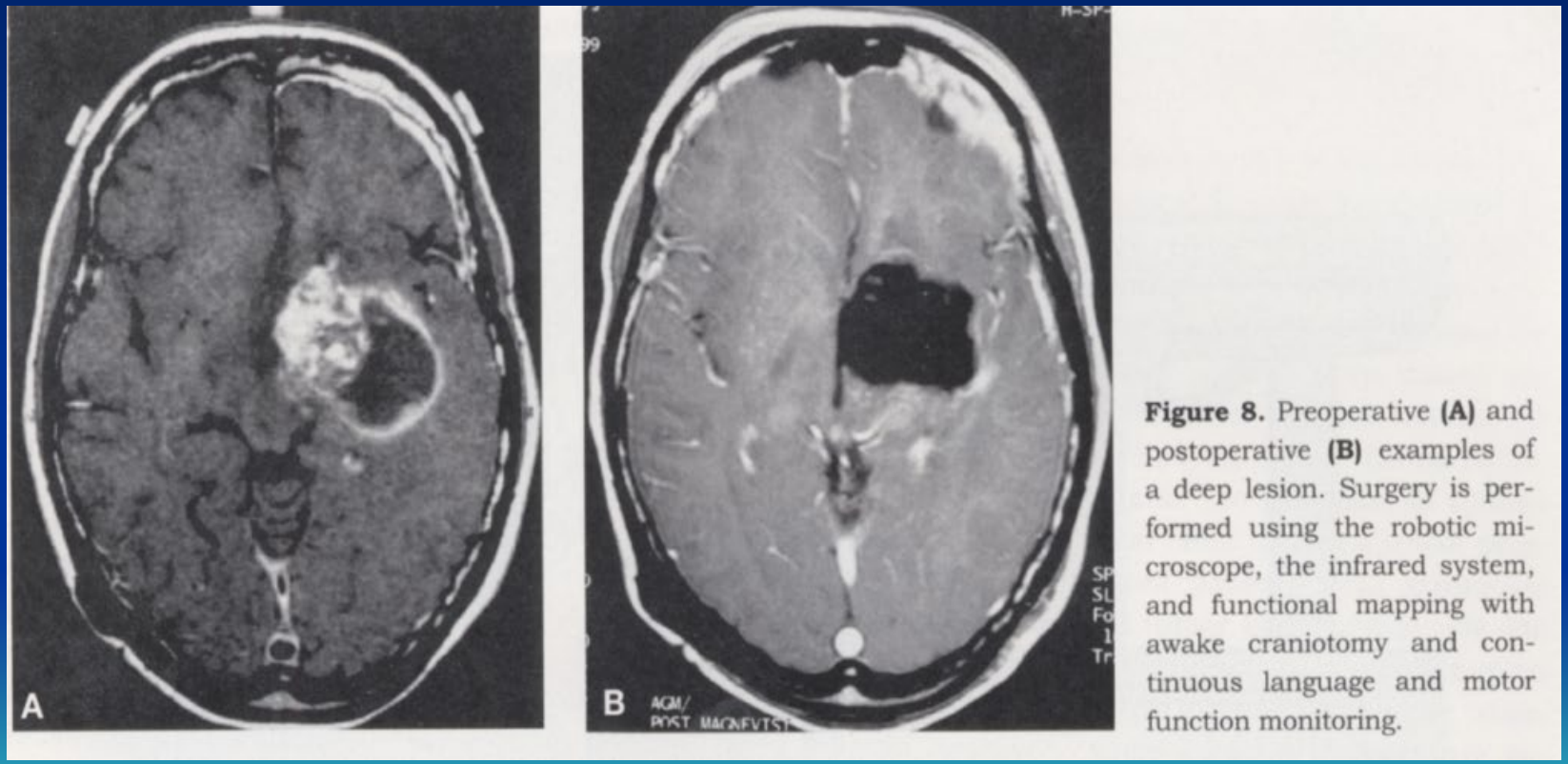


Figure 8. Preoperative **(A)** and postoperative **(B)** examples of a deep lesion. Surgery is performed using the robotic microscope, the infrared system, and functional mapping with awake craniotomy and continuous language and motor function monitoring.

Robotic Systems for Brain Neurosurgery

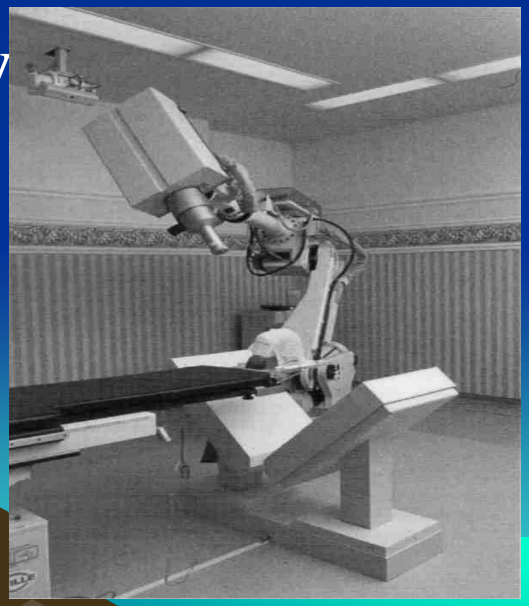
- Neuromate (Integrated Surgical Systems Inc. (USA), by Mayfield (USA) and finally by Renishaw (UK)
- ROSA system (Zimmer Biomet, USA)
- SurgiScope (ISIS Robotics, Saint Martin d'Heres, France)
- Renaissance system (MAZOR Robotics, Caesarea, Israel)
- NeuroArm robotic system (IMRIS Inc, Minnetoka, Minnesota)
- Small footprint systems: Autoguide (previously known as iSYS1) and the Brainlab Cirq,

Robotics in Radiosurgery

- Gammaknife
  - U Unit evolve into B Unit where the loading of Cobalt source was done using a robot arm
  - Unit C included a robotic positioning system (APS) . 4C with robotic retrofit
  - LGK PERFEXION (LGK PFX)was done to reach all targets using the robotic mode: the bed became the robot.
  - LGK Icon added cone-beam CT technology to allow mask based fixation for hypo-fractionated SRS

LINAC Radiosurgery

- Role of Robotics in all Linac-based Radiosurgery systems: gantry positioning, automatic couch positioning, multi-leaf collimation aperture control
- CyberKnife Robotic Radiosurgery



Future of Robotics in Neurosurgery Preoperative Planning Phase

- Multimodality Data i.e. imaging, physiological and other novel modalities
  - Molecular Targeting
  - Functional Imaging Targeting
  - Imaging with Genomic information
- Machine Learning Techniques to optimize surgical and radiosurgical planning

Future of Robotics in Neurosurgery Intraoperative Phase

•Advanced Visualization and Display techniques such as Augmented Reality (AR) to display multimodality data.

•Computer controlled tasks and non linear movements , i.e. robot assisted craniotomies and resections

- Integration of robotics with interactive Tracking techniques such as infrared-based, sonic, magnetic or fiber optic systems.
- Optimize surgeon-robot-computer interface i.e. robotic platforms that incorporates the software planning

Future of Robotics in Neurosurgery Intraoperative Phase

- Artificial Intelligence, machine learning and advanced mathematical algorithms to update of imaging information to account for intraoperative changes and shifting.
- Haptic Perception
- Miniaturization: Robotic micromanipulators and micro robotics
- Tele-surgical Robot
- Higher level of autonomy, full autonomy?

Future of Robotics in Neurosurgery beyond the Operating Room

- Teleprescence
- Robots in Neurosurgical Training
- Robots for Rehabilitation and Assistance

Thank you

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