INTRAOPERATIVE MRI IN NEUROSURGERY

PRESANTATION BY

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INTRODUCTION

"… no technique in neurosurgery could be too refined, particularly in reference to the ability to localize lesions…"

Lars Leksell

Image-guided neurosurgery

substantial improvement in microsurgical treatment of tumors, vascular malformations and biopsy of small intracranial lesions

Drawback of image-guided neurosurgery

-Mainly uses ***MRI pictures, acquired preoperatively***, for planning of the operative procedure

-***Brain shift*** regularly occur during the surgical procedure due to tumor removal & CSF leak → a continuously changing intraoperative field → preoperative data does not provide any information.

- During surgery, the neurosurgeon left with information he gets with his eyes through the ***surgical microscope*** as well as his ***surgical experience.***

- Only intraoperatively acquired images provides information required to perform real-time intraoperative image-guided surgery.

Intraoperative ultrasound

handy, low cost, but other than localization of cystic areas of tumor, quality of image is poor.

Dedicated moveable intraoperative CT unit

good quality image/ ***Ionizing radiation***

Intraoperative MRI is future

excellent imaging qualities/ no risk of ionizing radiation,

HITORICAL ASPECT

- Ist intraop. MRI → ***1991*** by **Black *at el*** → Departments of ***Neurosurgery and Radiology*** of the ***Brigham & Woman´s Hospital*** of the ***Harvard Medical School in Boston*** and the ***General Electric Medical Systems.***

- ***Ist time*** installation in***1994***
  - ***Brigham & Woman´s Hospital***
  - ***University hospitals of Zürich, Oslo, Tel-Aviv***

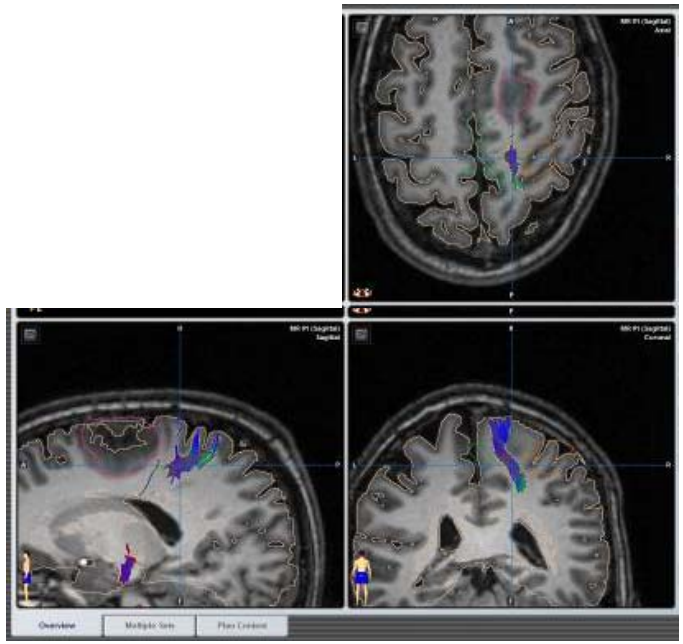
- Double-doughnut ***SIGNA SP system – 0.5 Tesla system***

- Ist MRI-guided ***stereotactic biopsy*** was performed in ***June 1995***

- Ist ***craniotomy*** for brain tumor removal using the intraop. MRI -***august 1996***

BOLD MRI

- It is a type of functional MRI, depends on the blood oxygen level.
- Blood oxygen level dependent MRI mapping of the functional area of the brain, modulated with anatomical images showing perceptual, motoric & cognitive areas of brain.
- Data can be integrated in OR for Image-guided surgery
- Provides more refined surgical approach



DIFFUSION TENSOR IMAGING

- A method of fiber tracking in white matter

- Based on random movement of water molecules in tissues

- Diffusion is larger in direction ALONG structure in tissue than its direction perpendicular to it

- Fiber tracking in tumors of motor cortex, basal ganglion, thalamus provides information regarding pyramidal fiber shift in reference to tumor

DEVELOPMENT & TYPES OF INTRAOP. MRI

- ***TYPES –***

I] Mild field system - < 0.5 Tesla system

A) ***Signa SP*** – 0.5 Tesla system

B) ***Magnetom – open system*** – 0.2 Tesla

II] High field System – 1.5 Tesla system

A) ***Sutherland & Calgary concept system***

B) ***Minipolis concept system***

C) ***Brain Suite***

III] Very Low field system – 0.12- 0.15 Tesla system

A) ***Odin PoleStar 10 system (0.12 T)***

B) ***PoleStar 20 System (0.15 T)***

IV] Very High field system - 3 Tesla system

MILD FIELD SYSTEM INTRAOP. MRI

SIGNA SP

- ***0.5 Tesla system***

- ***two vertically placed magnets***, oriented in a doughnut fashion

- leaving a gap of ***56- 60 cm***, providing the ***space for surgery***

- patient can be placed between the two coils of the magnet

- ***provide space for 1 or 2 surgeons***

- For ***RF*** transmission & receiving, ***a flexible head coil*** is placed in sterile operative field

- ***LCD monitor*** mounted in ceiling, provides images to the ***surgeon without leaving magnet***

- ***directly MRI-compatible instruments, including***
  - an anesthetic delivery system,
  - surgical instruments,
  - a high-speed drill system
  - an MRI-compatible surgical microscope

- ***Neurosurgical procedures***, that could be performed
  - real time ***MRI-guided biopsies***
  - ***"open-skull" procedures*** directly within the scanner

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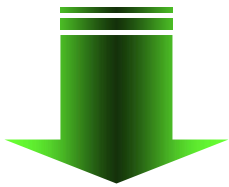
- Limitations & drawbacks

- patient positioning
- space and access to the patient for the surgeon & nurse
- compromised ergonomics, during long & complex operations
- the mandatory MRI compatibility of all instruments

- whether continuous intraoperative imaging was required ?



intraoperative MRI was required at different stages of surgery or at end of procedure

to detect any complication at the end of surgery

MAGNETOM- OPEN SYSTEM

- Also known as Erlanger and Heidelberg concept system

- ***Siemens*** & Departments of ***Neurosurgery*** of the ***University of Erlangen and Heidelberg***

- ***0.2 Tesla field system***

- Based on concept of ***"twin operating theatre"***

1) neurosurgical ***operations in a standard environment***, with standard ***MRI incompatible instruments*** and a standard surgical microscope

2) adjacent to a ***RF-shielded room equipped*** with a Magnetom-Open 0.2 MRI scanner.

- At any time ***during surgery the patient could be transported into the magnet***, e.g. for resection control

-***Time of transportation*** varied between ***20 - 40 minutes***

- Limitations & Drawbacks

- inferior image quality
- increased costs of installation of an independent operating and scanning site
- Extra cost of technical staff required through out the procedure
- Time-consuming patient transportation during surgery

LOW FIELD SYSTEMS

- Advantages

1) Integrated navigation system available

2) Real - time (interactive) surgery possible

3) Transportation may or may not be required

4) Wide variety of (interdisciplinary) surgical application

- Disadvantages

1) Special MRI- compatible (safe) instruments required

2) Image quality is inferior to higher field system

3) Positioning of patient is difficult

4) Narrow access to operative field (poor ergonomic)

5) High cost of system installation

HIGH FIELD SYSTEM INTRAOP. MRI

CALGERY CONCEPT SYSTEM

- concept was put forward in ***1999 by Sutherland*** and co-workers

- 1.5 Tesla system

- ***Use of a mobile ceiling mounted***, actively shielded 1.5 Tesla ***Magnet***

- ***Surgery is performed in a standard OR***

- ***Magnet is stored in an adjacent alcove separated*** from the operating theatre by closed doors

- At any point of time during surgery, if imaging was required then ***ceiling mounted magnet is craned in the OR***

- An RF tent is placed over the patient and parts of the operating table, and the scanning procedure is performed

- Advantages

- High quality image
- Additional functional capabilities of MRI
  - MR spectroscopy
  - functional MRI
  - MR angiography
  - chemical shift imaging
  - diffusion weighted imaging

- Disadvantages

- Real time surgery NOT possible
- Additional navigation system required
- Additional room for magnet storage & data update was required

IMRIS

-Based on concept of Calgary system

- ***difference is magnet is not stored , but utilized for diagnostic purpose***

- Two room concept – I) neurosurgery 2) Neurodiagnosis

- ***1.5 Tesla system***

- ***Use of a mobile ceiling mounted***, actively shielded 1.5 Tesla ***Magnet***

- Surgery is performed in a standard OR

- Magnet is stored between two rooms

- At any point of time during surgery, if imaging is required then ***ceiling mounted magnet is craned in the OR***

- Advantages

- High quality image
- MRI can be used for diagnostic purpose, improves cost-effectivity
- Additional functional capabilities of MRI
    - MR spectroscopy
    - functional MRI
    - MR angiography
    - chemical shift imaging
    - diffusion weighted imaging

- Disadvantages

- Real time surgery NOT possible
- Additional navigation system required
- Increased risk of infection

MINNEAPOLIS CONCEPT SYSTEM

- Proposed in year 2000, by ***Hall*** and co-workers from the ***University of Minnesota, Minneapolis***

- ***1.5 Tesla system***

- Shielded OR, with ***magnet & operation table are in SAME ROOM***

- Surgery is done with ***standard surgical equipments, BUT OUT SIDE 5-GAUSS LINE AREA***

- When required, MR- compatible ***operating table is shifted in the magnet***

- ***Time of transportation is 8-10 minutes***

- Advantages

- High quality image

- creation of an ***additional surgical or interventional area directly behind the magnet*** in which completely MRI-compatible instruments have to be used

- Additional functional capabilities of MRI

- MR spectroscopy

- functional MRI

- MR angiography

- chemical shift imaging

- diffusion weighted imaging

- Drawbacks

- Still transportation of MR- compatible table is required for few meters

BRAIN SUITE

- Developed by ***Seimens & Brainlab company***, in ***2003***

- ***1.5 Tesla*** field machine system

- High-tech operative environment, incorporating a dedicated surgical suite with a neuronavigation system & digitized image transfer and projection system.

- ***MAJOR DIFFIRENCE IS 180* ROTATING DEDICATED TABLE***

- Operation is done under ***standard operating environment***, with ***conventional instruments & microscope*** as patient is placed outside 5-Gauss line

- At any time during the operation, the surgical procedure can be interrupted, & the ***patient can be placed into the magnet by simply rotating the operating table***


Data Billboard
OR Lights, Ceiling Supply Unit and Anaesthesia Equipment
Microscope
Rotating OR Table
Head Clamp and 8-Channel OR Head Array Coil
iMRI screen
MAGNETOM - Espree 1.5 T

Rotating OR Table

Features

- Rotating table
- Flexible OR table positioning

Benefits

- High patient safety
- Straight forward workflow logistics
- No movement of anesthesia equipment
- Shortest patient transit time to and from scanner

Head Clamp and 8-Channel OR Head Array Coil

Feature

- „3 + 2“ point fixation design
- Adult and Pediatric 1-point fixation with gauge for orientation of applied pressure
- Two defined interfaces for Leyla Retractors
- Additional customized interfaces available
- 8-channel head array coil

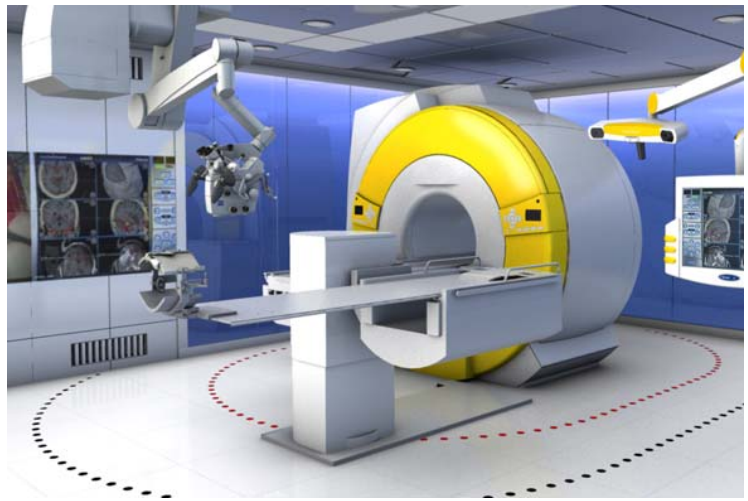
Benefits

- Higher degrees of freedom for more flexible patient positioning
- Better access to patient for intubation in prone position

MAGNETOM Espree 1.5 T

Features

- MR T1 and T2
- MR Angiography
- MR Spectroscopy
- fMRI / DTI



Benefits

- Superior diagnostic image quality
- Short image acquisition time
- State-of-the art technology and support
- Evaluating the utility of new MR-sequences
- Higher flexibility in patient positioning, fits larger patients
- Better access for increased patient safety

Microscope

Features

- Ceiling-mounted system
- Full navigation integration
- Advanced image injection

Benefits

- Avoids OR clutter
- Ergonomic user interface
- Facilitates easy patient transport
- Total neurosurgial control

OR Lights, Ceiling Supply Unit and Anaesthesia Equipment

Features

- OR lights with integrated video camera
- Ceiling Supply Unit with power, medical gases and signal lines
- MR-compatible anesthesia system, patient monitoring system and syringe pump

Benefits

- OR light video images can be displayed on Data Billboard
- Ceiling Supply Unit avoids OR clutter
- OR safety
- Special Anesthesia Equipment facilitates easy patient transport

Monitor

Features

- Ceiling mounted system
- Proprietary fiber optic wiring
- Computer system outside RF cabin
- Multifunctional control terminal

Benefits

- Flexible VV camera positioning
- Avoids OR clutter
- Avoids manual computer shutdown and restart
- Total neurosurgical control

Image Guided Surgery Cranial

Features

- Navigate simultaneously in different image modalities
- Universal and accurate instrument calibration on the fly
- Powerful image composer, combines all relevant anatomical details into one image set
- Direct touch screen access under sterile conditions
- Accurate laser registration based on the acquisition of a plurality of surface points

Software – Automatic Image Registration

Features

- No need to access anatomical landmarks
- Automatic marker detection
- Integrated data transfer
- Multiple image set handling

Benefits

- Accurate and fast image registration for workflow-oriented navigation on up-to-date intra-operative images

Surgical Planning Software

Software integration into one patient model

- BOLD MRI Mapping
- FiberTracking
- Functional Atlas Information
- Metabolic Information: SPECT, PET
- Angiography Information

Room Control System

Features

- Control of major electrical components
- Single button to change between surgery and scanning modes

Benefits

- Accessible from inside and outside the sterile field
- Easy to use
- Predefined scenario modes for scanning and microscopy

BrainSUITE Data Billboard

Features

- 3 x 57“ Flat-screen LCD Monitors
- Multiple monitor combinations available
- Superior resolution

Benefits

- Instant access to critical information
- Visible for the entire OR team
- Facilitates staff training and surgical decision-making process

iMRI RF Shielded OR Cabin

Features

- Advanced acoustic shielding
- Laminar air flow system
- Observation window
- Lighting and electrical distribution and control system
- Interior wall finish in stainless steel/glass
- Power and medical gas outlets

Benefits

- Room-in-Room concept
- Integration of all components
- Standardization of equipment positioning

- A separate operative area, directly behind the magnet can be used for interventional procedures

- Advantages

- High quality image
- Additional functional capabilities of MRI
  - MR spectroscopy
  - functional MRI
  - MR angiography
  - chemical shift imaging
  - diffusion weighted imaging

- Disadvantages

- expensive as regards installation and technical maintenance, as well as with regard to the necessary manpower and personal costs

HIGH FIELD SYSTEMS

- Advantages

1) availability of high field system

- Implementation of functional data
- Implementation of MR- angiography

2) use of routine surgical instruments

3) use of routine surgical positioning

- Disadvantages

1) Transportation of patient (except Brain suite)

2) Real- time (interactive) surgery NOT possible

3) Additional navigation system required

4) High cost of system installation & maintenance

VERY LOW- FIELD SYSTEM INTRAOP. MRI

ODIN POLESTAR 10 SYSTEM

- concept was put forward in 2001***by ODIN company & Department of Neurosurgery of the Sheba Medical Center Tel Aviv***

- 0.12 Tesla system, integrated with an optical and MRI tracking system

- ***Scanning and navigation, which are operated by the surgeon,*** *are controlled by an in-room computer workstation*

- ***Surgery is performed in a standard OR***

- scanner consists of ***two vertical, parallel, disk-shaped permanent magnets***

- ***magnets are fixed to a U-shaped arm,*** which is mounted on a transportable gantry***,*** which can be ***positioned under the operating table during surgery,***

- ***During scanning the arm is raised***, so that the area between the two magnets encompasses the head of the patient

- An ***special RF- shielding cage***, obviates the need any major constructional change in OR

- ***Advantages***

1) only moderate modifications of a standard operating room are necessary
2) standard neurosurgical instruments can be used
3) integrated tracking and navigation system allows for rapid and ***reliable intraoperative real-time navigation***
4) ***completely under the control of the surgeon***, obviating the need for radiological or assistant personnel.

- Disadvantages

1) Image quality is ***far from what is acceptable*** for routine intraoperative use
2) Application of functional imaging, spectroscopy or MRI angiography is ***not possible***

- It is seen more as ***a compact MRI guidance or navigation system***

POLESTAR N20 SYSTEM

- ***2nd generation PoleStar***

- ***0.15 Tesla system***, 27 cm distance between interpolar gap of magnet

- ***Scanning and navigation, which are operated by the surgeon,*** *are controlled by an in-room computer workstation*

- ***magnets are fixed to a U-shaped arm,*** which is mounted on a transportable gantry***,*** which can be ***positioned under the operating table during surgery***

- field strength fell below the critical threshold for use in an operating area***;*** ***no significant attraction is felt within 1 ft of the poles***

- ***The image quality is better than PoleStar 10 System***

VERY HIGH- FIELD SYSTEM INTRAOP. MRI

NAVIGUS SYSTEM

- Revised concept of Minneapolis Suite, forwarded in 2006 ***by Image-guided Neurologics, Melbourne, FL***

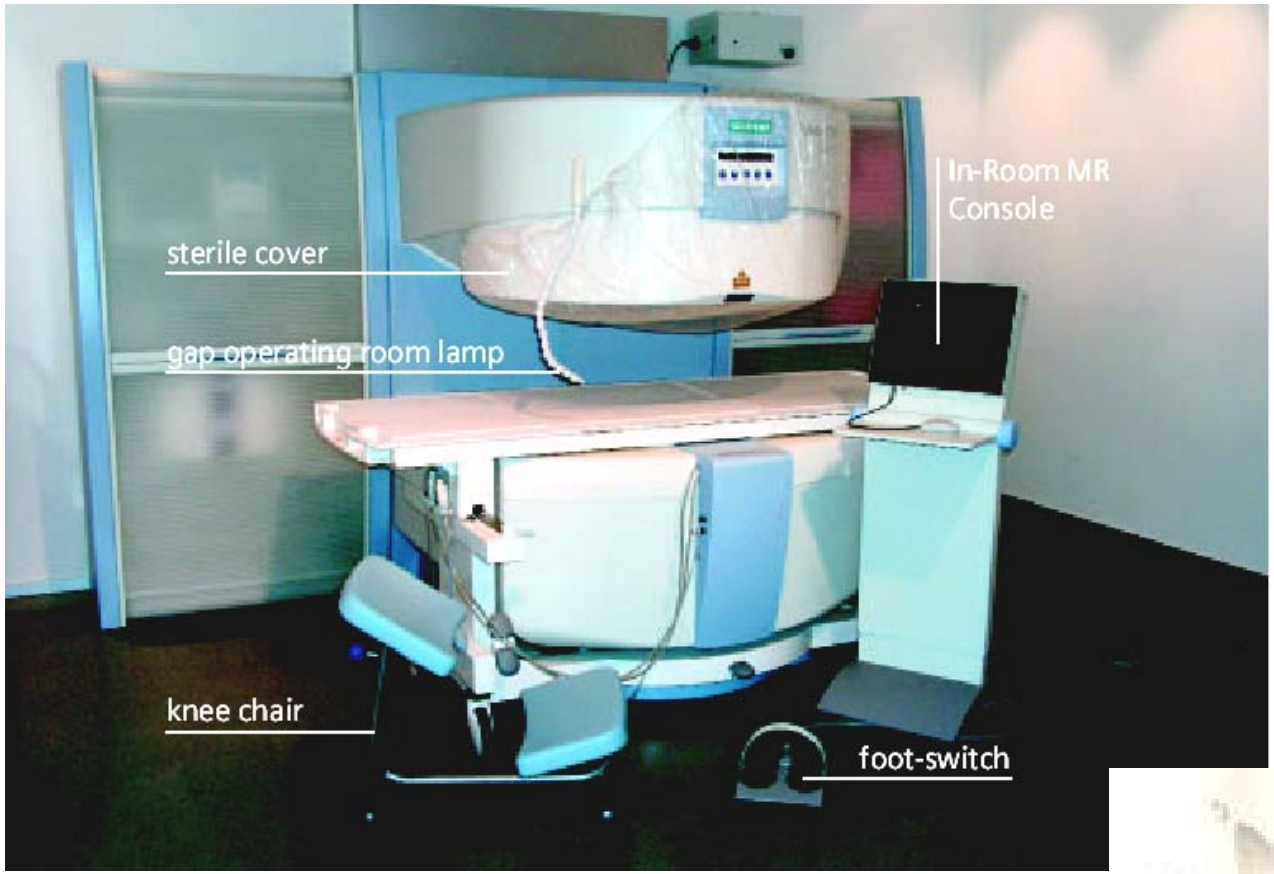
- ***3 Tesla system***, integrated with an optical and MRI tracking system

- ***Scanning and navigation, in a single room concept,***

- ***Surgery is performed in a standard OR, out side 5- Gauss fringe area***

-Patient is transferred in C- shaped MRI, on MR- compatible table

- Use of electrocautery, a fiberoptic headlamp, a power drill, and MRI-compatible neurosurgical cutlery is ***required for real time procedures***


In-Room MR
Console
sterile cover
gap operating room lamp
knee chair
foot-switch

- Advantages

- High quality image

- ***Being open magnet – Real- time tumor biopsy***
  - intraoperative cyst aspiration
  - Intralesional catheter placement

- Additional functional capabilities of MRI
  - MR spectroscopy
  - functional MRI
  - MR angiography
  - chemical shift imaging
  - diffusion weighted imaging

- Disadvantages

- expensive, requires 8-10 minutes time in transportation

- ***metallic artifact related to titanium needles*** is more challenging at 3 T than at 1.5 T- ***needle tip artifact, exhibits as a blooming ball***

PHILIPS MEDICAL SYSTEM

- *Department of Neurosurgery,* ***Cliniques Universitaires St-Luc, Université Catholique de Louvain, Brussels, Belgium*** & ***Philips Medical Systems, Best, The Netherlands, 2007***

- ***3 Tesla field system***

- Based on concept of ***"twin operating theatre"***

  1) neurosurgical ***operations in a standard environment***, with standard ***MRI incompatible instruments*** and a standard surgical microscope

  2) adjacent to a ***RF-shielded room equipped*** with a Philips-***cylindrical*** 3T MRI scanner.

- At any time ***during surgery the patient could be transported into the magnet***, e.g. for resection control

Intraoperative MRI Protocol

-T1- and T2-weighted fast spin echo
- fast fluid-attenuated inversion recovery

} -initial basic MRI protocol

- 3 types of T1-W sequences :
    1) a spin echo sequence covering the whole brain
    2) a gradient echo or fast-field echo sequence with thinner 3-mm slices
    3) 3-D fast-field echo sequence with 1-mm slices for ***multiplanar or coregistration purposes***

- echo planar imaging-gradient echo T2* for detecting and delineating ***acute bleeding areas in the operative area***

- DW imaging is performed
- accurately delineation of tumor extension
- to rule out acute ischemic damage

- TOF phlebograms to asses patency of the major venous channels adjacent to surgical area has to be assessed

- Advantages

- High quality image

- available to neurosurgeons for iMRI and for independent use by neuroradiologist ***– Interventional purpose***

- Additional functional capabilities of MRI
  - MR spectroscopy
  - functional MRI
  - MR angiography
  - chemical shift imaging
  - diffusion weighted imaging

- Disadvantages

- expensive
- requires - 78 ± 20 minutes more time, other than surgery
  - 34 minutes for MRI
  - 43 minutes for patient transportation
- increased risk of infection

CLEVELAND SYSTEM

- Developed by collaboration of ***department of neurosurgery, University Hospital of Cleveland & BrainLab and Medtronics*** in ***2006***

- ***Low- field system- 0.2 Tesla***

- ***Based on combined concept of Magnetom & brainLab with a single room system***

- MR- compatible, ***180* ROTATING & tiltable table***
- patient is operated outside the 5- Gauss area with conventional equipments

- Time spend in rotating operating table is 60- 90 seconds into gantry

- Patient with table is repositioned outside 5- Gauss in 1 minute duration

- ***Neuronavigation can be used***

- ***Being open magnet – Real- time tumor biopsy***
  - intraoperative cyst aspiration
  - Intralesional catheter placement

- *Intraoperative MR Imaging protocol*

fast imaging with steady-state precession (FISP)
steady-state free precession T2-W
reverse fast imaging with steady-state free precession (PSIF)

All craniotomies

3D and 2D T1-W FLASH gradient-echo sequences
T1-weighted spin-echo
T2-weighted turbo spin-echo (TSE)

Pituitary surgery

TSE FLAIR

Small residual tumor

- *Drawbacks*

MR angiography
diffusion-weighted imaging (DWI)
MR spectroscopy
brain activation and perfusion studies

Not Possible

- Duration of Intraoperative MRI (mean duration)

- Tumor resection – 35 minutes & 17 second/ op.
- Real – time brain biopsy - 200.57 minutes
- Real –time cyst aspiration – 54.66 minutes

INDICATIONS OF INTRAOPERATIVE MRI

- Supratentorial tumors- low grade glioma

- Transsphenoidal pituitary tumor resection

- Epilepsy surgery - side & size localization by functional MRI

- Resection control - cytoreductive surgery of large tumor

- Intraventricular shunt placement
- Needle biopsy – MS, mets
- Cyst aspiration

} Real- time surgery

- Electrode placement – deep brain stimulation

- After aneurysmal clipping – MR angiography

- Intramadullary spinal tumor resection

- For academic & experimental purposes

CONTRAINDICATIONS OF INTRAOPERATIVE MRI

- Ferromagnetic cardiac implant – heart valve

- Pace- maker (non- compatible)

- Steel implant fixation for bone fracture

- Ferromagnetic spinal implant

- Cochlear implant (non- compatible)

ADVANTAGE OF INTRAOPERATIVE MRI

- Improves the accuracy of craniotomy placement
- Reduce the size of bone flap
- Surgical navigation can be repeatedly upgraded by intraop. Imaging that detects brain- shift due to CSF leakage & parenchymal resection
- Reduces the chances of neurological deficit in the surgery of eloquent area of brain
- Identify any amount of residual tumor at the end of surgery
- Identify any residual hematoma in AVM surgery

PROBLEM & LIMITATIONS OF INTRAOPERATIVE MRI

- Highly expansive- 1.8- 3.5 million $

- Ferromagnetic objects, within 5- Gauss fringe field are risk for high speed missile into its bore & have serious consequences to the patient

- Needs large no. of technical staff for functioning & maintenance

- Can not be used for surgery in sitting position

- with high – field system- $\geq$1.5 T, there is artifact even with titanium needle

RESULTS & OUTCOME OF INTRAOPERATIVE MRI

- Different studies have wide range of outcome

- *On table residual tumor detection – 32- 67.5%*
  - it was grossly dependent on the surgeons experience, more senior surgeons have lower residual at the end of surgery
  - Many of the outcome/ result of tumor resection are financially supported by MRI companies

- *Increase in operating time – 36- 78 minutes*
  - depends on type of machine
  - Real- time surgeries like biopsy & cyst aspiration- 50- 200min
  - Also depends upon intraoperative MRI experience of surgeons

- Cost- effectivety – No were questioned

- Infection rate- No literature has directly correlated any of their case having infection due to introp. MRI related procedure

THANKS