Error analysis in neuronavigation
Application of CAS arm-system for navigation-guided cranial surgery
(Department of Neurosurgery, RWTH Technical University of Aachen 1990)
Application of CAS optical-system during endonasal navigation-guided surgery

(Department of ENT, RWTH Technical University of Aachen 1992)
Navigated Brain Surgery - Status Quo and Perspectives

Key issues: **Error analysis in navigated brain surgery**

- „Machine-made“ errors
- Strategical errors „Man-made“ errors
- Brain shift
- Intraoperative data refreshment
- Intraoperative workflow
- Education - Simulation - Training
Navigated Brain Surgery

Error analysis

Data acquisition

- Incompatibility of image data (CT, MR, DSA, PET, etc.)
- Data transfer problems (storage, disk drive, network)
- Slice thickness (extented investigation, motion artifacts)
- Image distortion errors (non-linearity of gradient fields)
- Artefacts (foreign bodies, magnetic susceptibility)
- Image reconstruction (accuracy of raw data)
Fusion - Matching of multimodal image data

CT - MRI

MRI - PET
Navigated Brain Surgery

Error analysis

Technical errors

- System inaccuracy (< 0.2 mm)
- Implementation of guided tools (plausibility checks)
- Hardware failures *due to high-tech in a hostile jungle* (system „abusers”, autoclaving of LED’s, cable breakage)

*Rare technical malfunctions, when systems are used adequately!*
Navigated Brain Surgery

Error analysis

Problems with fiducials

- Loss of adhesive skin markers (refixation by the patient)

- CT-markers have better registration accuracy (more defined and precise center or lower coefficient of spatial image distortion in CT-scanning)

- Bone screw fiducials (high accuracy vs. invasiveness)

- Tooth splint (repeatable, accurate and noninvasive)

- Marker-free contactless registration (surface-laser-scanning)
Navigated Brain Surgery

Error analysis

Registration errors

- Spatial arrangement of the skin fiducials (RMSE)
- Loss of rigid fixation of dynamic reference frame
- User dependent registration accuracy

Brain shift

- Tumor debulking, loss of CSF, sitting position, etc.
Intraoperative application

Craniotomy

Low grade glioma

Tailoring of craniotomy

Determination of resection
Intraoperative application

Temporal glioma
- Craniotomy planning
- Cortical approach
- Borderlines of resection

Heads-up display of segmented tumor size
Navigated Brain Surgery

Error analysis

Strategical errors

- Lack of experience and exact knowledge of the system
- Awareness of "virtual radiological reality"
- No on-line information
- No replacement for well-founded anatomical knowledge and for surgical experience

Surgeons have to know the multiple sources of error
Intraoperative navigation - pointer or microscope

Strategical error
Navigated Brain Surgery - Status Quo and Perspectives

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Navigated Brain Surgery - Status Quo and Perspectives

Brain shift

- Computer analysis with intraoperative MRI
- Vector graphics (vectors correlating length with force)

shift happens!
Navigated Brain Surgery - Status Quo and Perspectives

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Navigated Brain Surgery - Status Quo and Perspectives

Intraoperative CT-imaging

- Mobile CT (Tomoscan M, Philips Medical Systems)
- Cranial and spinal imaging (on-line data refreshment)
- Different „OR-table solutions” (restricted positioning)
- Problems of skull fixation (carbon head rest, special pins)
- X-ray (limitations)
- Work-flow analysis (cost : benefit and effort : benefit)
Intraoperative MR-imaging

- Experiences with over 8,000 cases (since March 1996)
- Intraoperative „high-quality“ data refreshment
- Special equipment (compatible instruments, microscope, etc.)

Excellent indications

- Resection control in glioma surgery
- Epilepsy surgery
- Transsphenoidal pituitary adenoma resection
- Therapy control in cryo- or laserablation
Construction design
Intracranial MR-guided biopsy in realtime

- Computer simulated workflow *(range of motion inside the gantry)*
Feasibility study – experimental „melon-test“
Phantom study – accuracy tests

- MR based planning and real-time controlled
- „Testflight“ to target (mean tolerance of precision < 0.5 mm)
Intraoperative ultrasound - Fusion with MRI
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Intraoperative orientation: Pointer - Microscope

3D graphical anatomical imaging of the topography

Planning of the adequate approach
Navigation-guided skull base surgery

- Heads-up display  (2D vs. 3D)
- High „passive accuracy“  (pointing-mode)
- Acceptable „active accuracy“  (working-mode)
- Modification of tracking of specific instruments
- Optimal graphical-anatomical orientation
- Virtual reality  Real virtuality
Navigated Brain Surgery - Status Quo and Perspectives

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Navigated Brain Surgery
Simulation - Education - Training

- Detailed preoperative planning (interactive learning)
- Microsurgical anatomy (multiplanar and 3D visualization)
- Approach and pathway planning
- Simulation of operations („unbloody surgical training“)
Computer animated anatomy - Interactive planning of surgery
Practical neurosurgical training – Simulation

Virtual neurosurgery
Virtual ventricular drainage

- Trajectory planning
- Length of the drainage
- „Freeze“ of the adjustment
- Opening of the monitor screen
- Interactive learning
- „Unbloody training“
Interactive neurosurgical training

Simulation - Virtual ventricular drainage

- 145 virtual VD
- 66 (46%) optimal position
- 79 (54%) malposition

<table>
<thead>
<tr>
<th>Ventr. index</th>
<th>drainage</th>
<th>optimal position</th>
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<tbody>
<tr>
<td>0.09 - 0.19</td>
<td>22</td>
<td>7 (32%)</td>
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<tr>
<td>0.20 - 0.49</td>
<td>32</td>
<td>15 (46%)</td>
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<tr>
<td>&gt; 0.5</td>
<td>6</td>
<td>5 (83%)</td>
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### Virtual ventricular drainage - Cumulative malpositions

<table>
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<th>Position</th>
<th>n</th>
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<tbody>
<tr>
<td>Nucleus caudatus</td>
<td>25</td>
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<tr>
<td>Corpus callosum</td>
<td>21</td>
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<tr>
<td>Contralateral ventricle</td>
<td>11</td>
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<tr>
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<tr>
<td>Contralateral callosal</td>
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<td>“My goodness“</td>
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Navigated Brain Surgery

Error analysis

- Experiences of totally 1796 navigated procedures
- Errors due to complex man-machine interaction!

16 machine-made errors vs. 112 man-made errors
totally, 128 failures (7.1 %)
erratum humanum est

„machines never err“