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Abstracts from the 3rd Meeting of the Intraoperative Imaging Society (iOIS)

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Abstracts from the 3rd Meeting of the Intraoperative Imaging Society (iOIS)

The 3rd Meeting of the Intraoperative Imaging Society (iOIS) was held in Zurich, Switzerland, from January 16 to January 19, 2011. This was an opportunity for clinicians and scientists working in the field of intraoperative imaging to exchange experience and knowledge. Internationally recognized experts presented and discussed technological advances, clinical applications, and socioeconomic aspects of intraoperative imaging. The editors of Computer Aided Surgery are pleased to present the abstracts for the oral presentations given during the meeting sessions.

Session I. Intraoperative MRI state of the art

Application of intraoperative MR spectroscopy at 3T to evaluate the extent of resection in low-grade glioma surgery (Invited presentation).

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Introduction: Outcome after Low Grade Glioma (LGG) resection has a direct correlation with the extent of resection. We have shown that 3T intraoperative MRI can increase the extent of resection. After resection of the main tumor, a T2 hyper-intense signal around the tumor resection cavity can warrant differential diagnosis between residual tumor and non-tumoral changes. Hereby, we tested the efficiency of intraoperative proton MR spectroscopy (MRS) and diffusion weighted imaging (DWI) to guide this differential diagnosis.
Methods: Ten patients with LGG, who had T2 changes around the resection cavity, were prospectively included in the study. All patients underwent intraoperative DWI and MRS imaging, and the results of MRS were correlated with biopsy of the suspicious area.
Results: Eleven (69%) of 16 T2 hyper-intense areas around the tumor resection cavity were histologically diagnosed as tumor. The sensitivity of intraoperative MRS was 81.8%, the specificity was 100%, the positive predictive value was 100%, and the negative predictive value was 71.4%. The specificity of intraoperative DWI for surgically induced changes was high (100%); however, the sensitivity was only 60%. A positive finding on ioDWI did not exclude the presence of residual tumor.
Conclusion: Intraoperative use of MR spectroscopy in 3T is effective in differentiating residual tumor from non-tumoral changes.

Experience with the 1.5T IMRIS System (Invited presentation)

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The authors describe a novel dual-room high-field intraoperative magnetic resonance imaging (iMRI) suite with a movable magnet, and analyze its efficacy with clinical experience of 500 cases. The iMRI suite consists of an operating room with an adjacent diagnostic room. A movable 1.5T magnet can be transferred between these two rooms. From February 2009 to November 2010, 500 cases (mean age 43.2 years; range 6–81 years) were operated in the operating room of the suite, while in the same period of time 3000 diagnostic scans were performed in the diagnostic room. The imaging data of all the operated cases were prospectively collected, and the impact of iMRI on surgery was analyzed. 391 craniotomies, 85 trans-sphenoidal surgeries, 20 frameless biopsies and 4 frameless ablations were performed. Of the 476 cases of lesion resection, iMRI revealed residual lesions in 142 cases (29.8%), resulting in the modification of the surgical strategy (e.g., further resection of the lesion). Eventually, 397 lesions (83.4%) were totally removed. Post-operative long-term morbidity is 4.8% (24 cases). With the MR suite, high-quality images, together with functional data, could be obtained intra-operatively. The intra-operative 1.5T MRI and functional neuronavigation can be successfully integrated into standard neurosurgical workflow. Intra-operative MR imaging can provide high-quality images and valuable information for intra-operative modification of the surgical strategy, while the dual-room setting can maximize the efficacy of the system.

Session II. CT and multi-modal intraoperative imaging techniques

Modern intraoperative neurovascular imaging

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Modern neurovascular surgery faces the rapid development of endovascular techniques, with the result that surgery becomes less popular and the vascular neurosurgeon encounters two major problems: the lack of experience usually gained with relatively simple cases, and the limitation of surgery to the more complicated vascular lesions. The combination of these two issues requires the development and implantation of technology to assist the surgeon for better results.
Intra-operative imaging in vascular surgery has three aims:

1. Navigation;
2. Flow patency on parent arteries - this is a unique task applied especially to vascular surgery and less so for tumor surgery;

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3. Clipping and resection control.

To allow these three aims, the NeuroVascular Neurosurgery team at Sheba Medical Center implanted four intra-operative modalities to the modern OR, namely intra-operative MRI, digital subtraction angiography, real-time ICG-based video-angiography, and microdoppler techniques.
The author will present and demonstrate the usage of those modalities, the required technology and resources needed, and the pros and cons of each modality.

Intraoperative use of portable computerized tomography and concomitant neuronavigation applications – a first year experience

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Aim: The usage of portable computerized tomography (CereTom, Neurologica) and neuronavigation (BrainLAB) in our institution was analyzed. The aim of the study was to report the efficacy of imaging performed in surgical settings.
Methods: Patient reports and computerized tomography data of the patients admitted between April 2009 and September 2010 were analyzed retrospectively.
Results: A total of 255 patients underwent imaging in our surgical setting between the aforementioned dates. Of these studies, the major field of use was early postoperative imaging (206 patients). CT guided neuronavigation was used in 33 patients, whereas intra-operative CT imaging was performed in 16. With the help of early postoperative imaging it was realized that 6 of the 206 patients needed additional intervention because of surgical complications. When the patients who were operated with CT neuronavigation or intra-operative CT acquisition were analyzed, it was seen that the majority of patients were operated on because of a mass lesion ($n = 27$ and $n = 12$, respectively). We have realized that with the help of intra-operative imaging one could achieve a more extensive and yet safer excision of mass lesions.
Conclusions: Imaging done during or immediately after surgical procedures reduces surgery-related morbidity and mortalities. One of those imaging modalities is computerized tomography. The main advantage of operative imaging done via CT over MRI is its convenience in terms of rapidity, low costs and its selectivity over blood products. Further studies should be conducted to display the correlation of intra-operative CT imaging with other modalities like MRI to argue its reliability in terms of complete excision of mass lesions.

The utility of immediate post-operative CT imaging in predicting clinical deterioration after elective cranial neurosurgical procedures

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Background: The use of intra-operative CT (iCT) allows immediate post-operative acquisition of brain scans for radiological assessment. The aim of our study was to evaluate the predictive value of immediate post-operative scans on the clinical outcome of patients within 7 days post-operatively. This was defined as clinical deterioration requiring reintubation, re-admission to the ICU, re-operation or death.
Methods: We retrospectively reviewed all patients who underwent elective cranial neurosurgical procedures performed in the iCT from September 2007 to June 2010. Patients who had immediate post-operative scans performed were identified for review. Patients who underwent emergency operations were excluded as these patients were liable to have a complicated post-operative course related to their initial pathology.
Results: 290 cases were available for analysis. Clinical deterioration occurred in 14 cases (4.8%) within 7 days post-operatively. In 11 cases (3.8%), the cause of deterioration was unrelated to the initial intracranial pathology and was associated with complications arising from existing medical conditions. In the remaining 3 cases (1%), review of the CT findings showed features which suggested a possible risk of post-operative deterioration.
Conclusion: All patients in our study who had post-operative deterioration due to their initial intracranial pathology had ominous features on their immediate post-operative CT scan. This suggests that post-operative CT scans can be used to predict the subsequent clinical outcome. This, however, excludes high-risk patients who have significant medical co-morbidities and may deteriorate despite a satisfactory post-operative scan.

The Indian perspective on intraoperative imaging (Invited presentation)

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The initial experience in intraoperative imaging started in 1988 with the use of intraoperative ultrasound and crude methods of image guidance including Vitamin E capsules on the scalp along with the use of ultrasound.

We were the first to introduce image-guided surgery in India in 1995. Over the last 4 years more than 350 cases have been done using high field MRI in a rotating table. The early cases suggest that in about 30% of cases the surgeons changed their intraoperative decision.

Over the last 6 months the newer concept of the Miyabi table has been used at our Neurosciences Institute. We present our results on the different types of intraoperative imaging using ultrasound, the rotating table – intraoperative room and the 2-room Miyabi concept. The total experience is 4 years with MRI and 23 years with intraoperative ultrasound.

The earlier experience with the Miyabi concept suggests significant advantages over the rotating table concept, including ease of surgery and ease of transfer with no significant difference in the time taken.
Conclusions: Our experience shows that intraoperative imaging with neuronavigation including iMRI could be successfully implemented in developing countries like India. Our initial experience suggests significant advantages of the 2-room Miyabi concept over iMRI with a rotating table.

Intraoperative navigation for minimally invasive resection of periarticular and pelvic tumors

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Background: Approaching symptomatic benign, metastatic, and some low grade primary malignant tumors is often a difficult undertaking due to their typically precarious locations. The treatment with regard to surgical approach and preservation of functional peritumoral anatomy is a formidable opponent when biopsying and treating these tumors.
Methods: We present a series of cases where intraoperative ''stealth navigation'' was used successfully to treat five patients with peri-articular tumors located in precarious anatomic locations.
Results: All of the patients in this case series with peri-articular tumors had an excellent post-operative Musculoskeletal Tumor Society Functional Score (range 26–29) after surgery. There were no surgery-related complications. One of the five patients had tumor recurrence months after the first operation and was treated successfully with a repeat operation with no complications noted.
Conclusion: The use of paired point imaging with image fusion (intraoperative computed tomography scanning with navigation synched to the image) has made approaching tumors through a minimally invasive and astoundingly accurate technique a reality. The advantages of these minimally invasive techniques are many, especially with regard to tumors that would otherwise require extensive dissection, soft tissue stripping, joint dislocation, and insult to the peri-articular blood supply.

Tumor bracketing and safety margin estimation using multimodal marker seeds

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Aims: One of the main reasons for locoregional treatment failure in breast cancer is the inability to fully excise the primary tumor during surgery. An approach that optimizes the surgical precision can have a positive influence on the clinical outcome. One approach to improving surgical guidance is the preoperative placement of markers around the tumor. The challenge here is to generate marker seeds that (1) can be placed accurately at different positions surrounding the tumor; (2) can be preoperatively detected with non-invasive imaging techniques; (3) can be relocated during surgical procedures; and (4) will also provide post-operative guidance for pathologists.
Methods: To achieve all this, we have generated multimodal tumor marker seeds that are based on a ''cocktail'' of a dual-emissive inorganic dye, lipids, and pertechnetate. The potential of these seeds was evaluated in a phantom wherein a surrogate tumor was placed [1].
Results: Due to their contents, the multimodal marker seeds can easily be placed under ultrasound guidance and detected afterwards with X-ray imaging, single photon emission tomography, magnetic resonance imaging, and fluorescence imaging. Placement of several markers around the surrogate tumor also enables 3D bracketing of the entire lesion. Furthermore, the two emissions of the dual-emissive inorganic dye (the exciton and the defect emission) [2] give the unique opportunity to also determine the depth of the seeds via multispectral imaging; exciton emission (520 nm) <5 mm penetration, and defect emission (open filters) <12 mm penetration.
Conclusion: The multimodal marker seeds may aid surgeons in the resection of tumor using a safety margin >5 mm. Furthermore, when using seeds with different (fluorescent) colors, the original geographic orientation of the excised tissue can be determined.

1. Buckle et al. Journal of Biomedical Optics 2010:15;056021.
2. Chin et al. Biomaterials 2010:31;6823.

Session III. Intraoperative imaging for spine surgery

Advanced techniques for imaging of the spinal cord (Invited presentation)

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The past ten years have witnessed a revolution in the diagnosis and management of spinal disorders. MR imaging has quickly emerged as the study of choice for virtually all disorders of the spine. With the inherent contrast sensitivity, the high spatial and temporal resolution, the multiplanar sampling of anatomy, the reliable differentiation between normal and pathologic tissue, and the lack of irradiation hazards of MR, the morphology of the spinal cord and nerve roots, but also of the vertebrae, intervertebral disk, and epidural space, can be visualized with striking clarity. The use of paramagnetic contrast agents has become well established in a variety of disorders, allowing definition of abnormal vessels, leptomeninges, and disrupted blood-cord barrier. State-of-the-art MR has increased the specificity of diagnosis of spinal disease, aided earlier diagnosis of spinal lesions, and increased the anatomical precision of disease localization. Diagnostic innovations have been followed by considerable therapeutic advances, but therapeutic advancements, particularly in the field of regeneration of the neural tissue in spinal cord injury, are also driving technological developments in imaging. New imaging methodologies have been developed over the last few years that are used to clarify not only morphological changes but also the physiology and pathophysiology of neural tissue.

At present, the application of advanced imaging methodologies for *in vivo* imaging of the human spinal cord is gaining widespread acceptance for potential use in clinical studies. These include high-resolution differentiation between spinal cord gray and white matter using high field (3-T) MR systems, evaluation of microstructural changes in the integrity of white matter using DTI, and mapping functional activity of the spinal sensorimotor neurons using fMRI, as well as metabolical imaging of the spinal cord tissue using MR spectroscopy. The first clinical applications in patients with demyelinating disease, (i.e., multiple sclerosis), spinal cord injury (SCI), neoplastic processes, etc., indicate that these techniques provide better demonstration of the structural damage and understanding of its functional consequences and its evolution in the human spinal cord. Quantitative imaging parameters can be used as surrogate markers of disability for determining prognosis and for following up rehabilitation and pharmacologically induced recovery. With the progression of regeneration-enhancing treatment for spinal cord injury from basic research to patient trials, these new diagnostic tools for clinical assessment, including prognosis and post-treatment follow-up, have become of the utmost importance for assessing with increased specificity and sensitivity the structural, physiological and functional status of the human spinal cord *in vivo* and in the clinical setting.

It must be always remembered, however, that the body has a limited range of responses to an apparently infinite variety of insults from infectious, inflammatory, traumatic, and neoplastic entities. Images are often sensitive but not specific, and a logical pathologic differential diagnosis must be given. Further, many morphologic derangements can be demonstrated in asymptomatic individuals, which further complicates the concept of abnormality. In certain situations there may be only a moderate correlation between the imaging evidence of morphologic alteration and the presence of symptoms. These facts emphasize that we need to concentrate more effort on determining the significance of the morphological changes that we can now demonstrate so exquisitely, and the central importance of both the clinical and electrophysiological evaluation in the work-up of patients with spine disorders. Imaging is an intermediate test that must be

integrated into, rather than isolated from, the clinical and neurophysiological evaluation. The management of patients with spinal disorders must begin and end with a thorough clinical assessment, and imaging findings must be correlated and validated with clinical and electrophysiological parameters.

Role of the O-Arm and neuronavigation in the management of complex spine surgery cases

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Introduction: The type and extent of surgeries carried out for complex spine disorders still lack evidence-based medicine proof. It is up to the health care provider's sound judgement and expertise to do what is needed for the patient. Surgical challenges include, but are not limited to, decompression near vital vascular or neural structures, decompression at a blind angle, and difficult trajectories for instrumentation. The use of intraoperative CT-quality O-arm and neuronavigation are still being tested as aiding tools in such operative modalities.
Methods: We randomly selected 50 cases of complex spine modalities that were operated upon at our institute during 2009 by the first two authors for inclusion in this retrospective study. Cases included traumatic spinal fractures and infective, inflammatory, benign and malignant neoplasms affecting different parts of the spinal column. All of them had technical challenges regarding the adequacy of decompression or safety of instrumentation. All had undergone a combination of decompression and instrumentation of different modalities and/or bone grafting. In all cases, the Medtronic O-arm® and Medtronic StealthStation® were used as intraoperative mapping tools.
Results: Intraoperative navigation tools were useful in securing adequate neural decompression and neural and vascular tissue safety, together with tough bony purchases of the hardware from the first and only trial application. Intraoperative CT taken by the O-arm was a useful confirmatory intraoperative test of proper hardware placement.
Conclusion: The intraoperative use of the O-arm and StealthStation is very useful in different modalities of complex spine surgeries. Intraoperative confirmation of the proper hardware placement by intraoperative CT is of the utmost value in completing the procedure.

Placement of thoraco-lumbar pedicle screws using O-arm-based navigation: technical note on screw placement and on controlling the operational accuracy of the navigation system

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Background: Suboptimal placements of pedicle screws may lead to neurological/vascular complications, potentially requiring reoperation. Computer-assisted image guidance has been shown to improve accuracy in spinal instrumentation. We describe our procedure of using O-arm-based neuronavigation to place pedicle screws in the thoraco-lumbar region in a minimally invasive fashion, highlighting our technique to continuously maintain the operational accuracy of the navigation system.
Methods: A total of 62 pedicle screws were inserted in 10 patients using a stepwise algorithmic combination of O-arm-Stealth navigation. Micro-screws to serve as internal fiducials were inserted in the spinous processes of interest prior to acquisition of the navigation dataset. These micro-screws were used to assess at will the operational accuracy of the system during surgery. All patients underwent a post-operative thin-slice control CT scan of the instrumented area. Follow-up ranged from 4 months to 24 months (mean and median 20 months). The Mirza evaluation system was used to evaluate the accuracy of the position of the inserted screws.
Results: We placed 26 thoracic and 36 lumbar screws in 10 patients. No patient experienced any complication related to pedicle screw placement. None of the screws needed to be repositioned after surgery. The post-operative thin-slice CT showed that the accuracy of the screw placement, according to Mirza's system, was 100%.
Conclusion: Using our proposed algorithmic stepwise technique of utilizing the O-arm and StealthStation, the accuracy of screw placement is dramatically enhanced, and the need to bring a patient back to the operating room to reposition a pedicle screw, as well as anatomical injuries, are virtually eliminated.

Clinical study on accuracy measurement of neuronavigated O-arm image-guided surgery of the thoracic spine

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Introduction: Image-guided navigation has reportedly increased the accuracy and safety of pedicle screw insertion and decreased complication rates. In previous studies, the result of image-guided navigation was mainly compared qualitatively with the result of conventional fluoroscopy-guided procedures. The present clinical study aims at measuring in a clinical setting the accuracy of the O-arm (3D imaging device) coupled to a neuronavigation system. This is done by digitally overlapping the image of the virtual position of a needle tip displayed on a navigation system after percutaneous introduction into a thoracic vertebral body during a vertebroplasty procedure with the real position of the needle tip when using O-arm intraoperative acquisition.
Methods: Forty-eight Jamshidi navigable needles were placed through a unilteral extrapedicular approach into fractured vertebral bodies of thoracic T10-L2 levels using O-arm guided navigation. The navigated needle tip positions were compared with the real needle tip positions from 3D O-arm volumes acquired after immediate completion of the needle procedure. A dynamic reference frame was attached to the iliac crest. Both digital images acquired during the procedure were overlapped and deviation measured.
Results: The mean difference between the navigated needle position and the actual needle position was 0.8 ± 0.3 mm.
Conclusions: Accuracy of O-arm guided navigation is high even in a clinically relevant setting and superior to the accuracy reported in other studies.
Learning objectives: This study provides a quantitative evaluation of the accuracy of O-Arm guided needle placement in thoracic percutaneous vertebroplasty.

Posterior spinal fixation using fluoro-CT-guidance and assisted by a navigator: Experience in 110 cases

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Introduction: We present a series of 110 cases of posterior vertebral fixation from September 2008 to October 2010 using fluoro 2D-CT assisted by a navigator.
Material and methods: The sample included 61 males and 49 females. Age range was 24–75 years with an average of 50.57 years. All had indications for fixation for different pathologies. All underwent a CT scan before surgery, according to the navigation protocol, and the images obtained were merged with fluoro 2D images in the navigator in the operating room. To evaluate the results of the implant, a post-operative CT was performed and the position of the implant was defined according to the Heary scale. The calibration time of the material and the number of shots with the fluoro 2D was also evaluated. For clinical evaluation, VAS scales, Oswestry and JOA lumbar were employed, as well as the degree of satisfaction and acceptance of a repeat procedure.
Results: A total of 532 screws were implanted: 54 cervical, 38 dorsal, 340 lumbar and 100 sacral. Open surgery was performed in 38 cases, MIS in 27 and percutaneous in 45.The precision of the implant was 98.31% with a global deviation of 1.69% according to the Heary scale. Average time of surgery and recording was 3 h 14 min and 2 min 45 seconds, respectively. The mean fluoroscopic exposure was two shots. The clinical evaluation at one month of 100 patients was 8.6/3.0 in the VAS, 68%/23% in Oswestry, and 6.4/13.11 in JOA (L), these parameters remaining stable at 6 months in 76 patients. The degree of satisfaction with the procedure was 95.4%, and 95.3% said they would submit to another treatment.
Conclusion: Navigation with fluoro-2D CT is a high-precision technique that reduces complications of varying severity according to the level operated, as well as the number of reinterventions, radiation exposure, and so on.

Occipital junction fixation and the role of iCT navigation (Invited presentation)

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Occipital junction fixation is performed for instability and complex pathology in the cranio-cervical junction (Occiput to C1, C2). Common causes include trauma, tumors, infections, and rheumatoid arthritis. Instrumentation in the craniocervical region has significant risks, as there are critical structures located close together, e.g., the vertebral artery, torcula and cerebellum. Traditionally, insertion of instrumentation is done guided by intra-operative fluoroscopy, but incidents of screw malplacement can occur in up to 25% of cases. In our institution, we utilize the intra-operative CT with spine navigation and autoregistration to aid instrumentation.
We conducted a study of Asian patients and found the average C2 pedicle diameter to be 5 mm. This is smaller than in studies on European patients. Results from our series of C2 pedicle screw fixation were good. There were 10 patients who underwent screw insertion under iCT guidance, with only 1 case of mild (grade I) screw breach (5.8%). There were no cases of vertebral artery injury. We conducted a CT-based study of Asian patients with respect to the occipital bone anatomy and midline keel bone thickness. This ranged from 10 to 11 mm at the sub-inion region, which is thinner than in European patients.
Results from our series of 10 patients who underwent occipital midline keel fixation were good. There were 7 adult patients and 3 pediatric patients. There were no cases of CSF leak or post-operative extradural hematoma.
In summary, intra-operative CT scanning can improve the safety and results of occipital-cervical junction instrumented fixation. Further large-scale trials will likely demonstrate this.

Session IV. iOI & mapping / hybrid OR

Brain mapping, hodotopy and plasticity: new concepts in the surgery for low-grade gliomas (Invited presentation)

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The goal of surgery for low-grade gliomas is to optimize the extent of resection, while minimizing the risk of permanent deficit. Because tumors often invade ''eloquent areas'', and due to a major inter-individual anatomofunctional variability, the cortical functional organization, the subcortical connectivity. and the brain plastic potential should be studied for each patient. Functional neuroimaging (FNI) and tractography show the relationships between the tumor and eloquent regions, but FNI has methodological limitations. Consequently, intraoperative electrostimulation mapping (IES) is increasingly used. IES is performed in the awake patient for sensory (-motor), visuo-spatial, language and cognitive mapping. This is an easy, accurate, reliable and safe technique for detection of cortical areas, white matter pathways and deep grey nuclei crucial for the function. IES enables one to study individual cortical functional organization before resection; to understand the pathophysiology of ''eloquent'' areas; to map the subcortical structures throughout the resection; to analyze the mechanisms of on-line plasticity; and to tailor the resection according to individual cortico-subcortical functional boundaries. Moreover, IES can be combined with repeated pre-and post-operative FNI, to validate FNI, and to study the functional reorganization over time. Such plastic potential opens the door to multiple surgeries spaced by several months/years to optimize the benefit/risk ratio of surgery, i.e., to increase the extent of resection while preserving or improving the quality of life. IES is a unique tool to improve our knowledge of brain processing and to revisit the classical model of cognitive neurosciences, by switching from a localizationist to a ''hodotopic'' view of cerebral organization. Above all, from an oncological point of view, the use of IES has enabled surgeons (1) to extend the surgical indications in eloquent areas classically considered ''inoperable'' (e.g., Broca's area or the insular lobe), and (2) to significantly increase the extent of resection and thus the impact on the median survival by delaying the anaplastic transformation, while (3) preserving or even improving the quality of life of patients (80% control of intractable epilepsy). In summary, surgery is now the first option to consider in low-grade gliomas.

Multimodal navigation and iMRI (Invited presentation)

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Data from magnetoencephalography or functional MRI localize cortical functional eloquent brain areas, while tractography based on diffusion tensor imaging allows visualization of the course of major white matter tracts like the pyramidal tract, the visual pathway, and speech-related pathways. Besides these functional data, further information is available for a multimodal navigation set-up. Positron emission tomography, MR spectroscopy, and diffusion weighted imaging provide information on the diffuse tumor border. Integration of metabolic maps into the navigation datasets enables a spatial correlation to histopathological findings. Multimodal functional navigation enables removal of a tumor close to eloquent brain areas with low postoperative deficits, whereas additional intraoperative imaging ensures that the maximum extent of the resection can be achieved and updates the image data, compensating for the effects of brain shift. With intraoperative imaging, the unexpected finding of residual tumor in postoperative examinations is practically eliminated. As a consequence, the surgical goal of a complete or an optimal resection can be achieved without any guesswork. In about one third of all procedures intraoperative MRI results in a change in the surgical strategy, i.e., further resection. Due to the combination of multimodal navigation with intraoperative imaging, the optimal extent of a resection by simultaneous preservation of functional integrity can be achieved. Intraoperative imaging beyond standard anatomic imaging, especially intraoperative DTI, adds further safety for complex tumor resections.

Clinical benefit of a combined surgical and imaging suite based on flat-panel technology for surgery of cerebral aneurysms (Invited presentation)

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Background: A consecutive series of n = 70 patients underwent microsurgical treatment of their intracranial aneurysms in a combined imaging and surgical suite which allows for diagnostic as well as intraoperative imaging (CT and 3D rotational angiography, RA). Therefore, recent flat-panel technology (Philips Allura Xper FD 20) is installed within a sterile surgical and neuro-interventional environment. It allows for combined neuro-interventional and open surgical approaches with intraoperative high-speed CT-like imaging and intraoperative 3D rotational angiography (up to 620 projections along 240° in 8–10 sec, rotational speed: 30°/55°/s, 30 frames/sec), automated segmentation of vascular structures, and intraoperative update of a frameless navigation system (Brainlab VectorVision II). The impact of intraoperative imaging on treatment strategy, workflow and feasibility of this set-up was evaluated using a prospective database.
Results: In 20% (n = 14) of patients intraoperative 3D RA has led to re-positioning of the clip(s), due to visualization of neck remnants of the aneurysm, or of compromise of parent and/or branching arteries. Consequently, all aneurysms were clipped completely. In one patient, intraoperative superselective thrombolysis had to be performed after thrombus formation. For infrastructural reasons, n = 6 patients (n = 7) recently had to undergo aneurysm surgery in a conventional emergency operating room. Intraoperative difficulties were encountered in two patients, and aneurysm remnants were detected on postoperative 3D RA in two patients. Although this is being speculative, it is assumed that these cases could have been managed in a better and more effective manner in the dedicated hybrid room.
Conclusion: A combined neurointerventional suite based on flat-panel technology is of particular value for treatment of cerebral aneurysms. It improves the overall management of such neurovascular surgery in terms of the (peri-)interventional workflow, and by avoiding the necessity for extraoperative angiographic control with the potential need for revision in a second operation.

Session V. Intraoperative imaging for benign lesions

Outcome of iMR tomography-assisted transsphenoidal microsurgical pituitary surgery in patients with acromegaly

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Background: Acromegaly is a rare disease in most cases caused by a growth hormone (GH)-producing pituitary adenoma (PA). Surgery is generally recommended as first-line treatment. Transsphenoidal surgical techniques were recently improved by the introduction of endoscopy and intraoperative low- and high-field magnetic resonance imaging (iMRI).
Objective: The aim of the present study was to analyze the impact of intraoperative ultra-low-field MRI for tumor resection control, complication avoidance and endocrinological and neurological outcome.
Methods: A series of 39 consecutive cases receiving transsphenoidal iMRI-guided surgery (PoleStar N20) between September 2005 and August 2009 for GH-producing PA was retrospectively analyzed. General patient data, endocrinological parameters, neurological examinations and pre-/post- and intraoperative imaging were evaluated.
Results: Thirty-seven patients with symptoms of acromegaly underwent 39 transsphenoidal surgeries for pituitary adenomas. Patients' median time of hospitalization was 7 days. During follow-up (median 30 months) there were 30 cases (76.9%) with normalization of preoperative elevated GH- and IGF-1 levels. With additional evaluation of symptoms of acromegaly, the postoperative imaging and glucose tolerance test rate of cure in patients with primary surgery was 73.5% and the cure rate in patients with previous surgery was 20.0%. The overall cure rate was 66.7%. There was no case of major complication requiring reoperation.
Conclusions: This study shows that iMRI guided surgery for GH-producing PA is a highly effective treatment modality in the therapy of acromegaly. Results of this so far largest study analyzing iMRI-guided transsphenoidal surgery in GH-producing pituitary adenomas are at least as good as in previously published series. Ultra-low-field iMRI seems to provide adequate information regarding tumor removal. Detection of tumor remnant and additional tumor resection led to a 5.1% increase in the cure rate. More research and larger study groups are necessary to analyze the advantages and limitations of this method.

iMRI guided endonasal endoscopic transsphenoidal pituitary surgery

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Objective: The two most recent significant advances in pituitary surgery have been the endonasal endoscopic approach and intraoperative magnetic resonance imaging (iMRI). The aim of the study is to discuss the impacts of combining the two techniques in pituitary surgery, especially the extent of tumor resection and the complication incidence.
Patients and methods: Fifteen patients with pituitary lesions have been operated using an endonasal endoscopic approach guided by iMRI in our center. Six patients had non-functioning pituitary adenoma, 3 had acromegaly, 3 had prolactinoma, 2 had craniopharyngioma and one patient had Cushing's disease. Preoperative and IMRI images were obtained in all cases.
Results: In 5 patients iMRI demonstrated the presence of residual tumor which was resected endoscopically before the completion of surgery, helping to achieve a total or near-total excision of the lesion. In two other cases, potential residual tumor was examined endoscopically and found to be normal postoperative change. Total or near-total excision was achieved in 14 patients (94%), with subtotal excision in only one patient. Three patients had CSF rhinorrhea postoperatively, which was managed conservatively by nasal packing and lumbar drain. No major intraoperative complications were encountered in our series.
Conclusions: Combining iMRI with endoscopic transsphenoidal surgery for pituitary lesion is feasible and increases the safety of the procedure. Each technology provides complementary information, which can assist the surgeon in safely maximizing the extent of tumor resection.

Uninostril endoscopic transnasal transsphenoidal surgery for sellar pathologies with supra- and parasellar extension

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Background: Endoscopic surgical procedures have gained wide acceptance in the treatment of sellar lesions. Most surgeons use the four hands two nostrils approach. We hereby report our experiences with the unilateral (one nostril) endoscopic approach for the treatment of (peri)sellar lesions.
Methods: In a period of 23 months (December 2008–October 2010), 46 consecutive patients (45 adults, 1 child; 22 males) were operated via a uninostril transnasal transsphenoidal approach with the use of a rigid endoscope (0° or 30°, Karl Storz, Germany) to treat (peri)sellar pathologies (36 pituitary adenomas, 1 recurrent myopericytoma, 1 recurrent craniopharyngeoma, 3 abscesses, 1 Rathke cleft cyst, 1 chordoma, 1 meningioma, 2 others). Twenty-seven patients had suprasellar and 22 parasellar extension. Complete pre- and postoperative neuroradiological, endocrinological and ophthalmological status was documented in a database.
Results: Total resection was achieved in 21 patients (55%). In 8 patients possible tumor remnants or scar tissue were indistinguishable, while 9 patients (24%) showed residual tumor. A uninostril endoscopic approach was possible in all cases except for the patient with a meningioma, where the approach was extended via the other nostril so as to have better instrument maneuverability. Overall, 5 patients (11%) suffered from complications. Two patients were reoperated because of postoperative bleeding (1 epistaxis and 1 hematoma in a case with spontaneous bleeding into an arachnoid cyst while the patient was on oral anticoagulation). One patient had a late CSF leak leading to readmission 2 weeks after surgery because of meningitis. In the patients with recurrent myopericytoma an accentuated diplopia due to IVth nerve palsy was encountered. One patient suffered from postoperative DVT.
Conclusions: The endoscopic uninostril transnasal transsphenoidal approach is a minimally invasive surgical option to safely and effectively remove sellar lesions with a high degree of patient comfort and good clinical and radiological results.

Intraoperative 1.5T iMRI and neuronavigation in cerebral cavernous malformations. A single center experience.

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Aims: Current literature indicates that incomplete removal of cerebral cavernous malformations (CCMs) is associated with increased risk for future hemorrhage. The present study reviews the experience with intraoperative MRI (iMRI) and neuronavigation in the surgical treatment of CCMs in an attempt to define the indication and the potential value of iMRI in these lesions.
Methods: Retrospective analysis of 7 patients (3 males, 4 females; mean age 51 years) harboring 4 supratentorial and 3 infratentorial CCMs treated at a single institution between 2008 and 2010. CCMs presented with seizure (3), intracerebral hemorrhage (2), or as incidental findings (2) on neuroimaging studies. An associated developmental venous abnormality (DVA) was identified in one case on preoperative MRI. The surgical procedures were performed under microscope-based neuronavigation. The extent of resection was evaluated on 1.5T iMRI. In the case of suspected incomplete removal, surgery was continued and additional tissue was resected. iMRI findings were correlated with histopathologic studies.
Results: Neuronavigation was performed with high accuracy and total resection of CCMs could be achieved in all cases. In two cases iMRI revealed residual CCMs which were completely resected in a second step. The histopathologic studies confirmed the iMRI findings. Only one patient with a large CCM close to the pyramidal tract had a transient hemiparesis which resolved completely. In this case intraoperative diffusion tensor tractography showed a preserved pyramidal tract. The associated DVA in another patient which was additionally segmented for neuronavigation could be preserved.
Conclusions: The application of iMRI combined with neuronavigation in CCMs allows a less invasive surgical exposure and potentially increases the extent of resection. It can modify the surgical strategy for both micro- or macro-CCMs in supratentorial and infratentorial locations.

iMRI and meningioma resection

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Introduction: Intraoperative MRI (iMRI) ideally can be applied to the surgery of any patient with an intracranial tumor. Meningiomas are extra-axial tumors whose borders can almost always be defined by visual inspection. We analyzed our experience using iMRI on patients with meningiomas.
Methods: Surgery was done using the compact, mobile PoleStar N20 iMRI (Medtronic Navigation), based on a 0.15 Tesla magnet. iMRI was used if the specific OR was available and if there was no patient-related contraindication to its use (e.g., cardiac pacemaker, very large body habitus).

Results: Sixty-four operations for meningiomas were done on 60 patients. Of these, 34 operations were done on 33 patients for tumors that were above the skull base (Group A – 13 parasagittal, 12 convexity, 5 anterior falcine, and 3 intraventricular), and 30 on 28 patients with skull base tumors (Group B – 12 midline anterior, 12 sphenoid wing, and 8 lateral posterior fossa). In 4/34 Group A surgeries, intraoperative imaging led to additional tumor resection; in one patient with a deep falcine tumor, unnecessary dissection was avoided after imaging confirmed complete resection. In one patient with a falcine tumor further resection after imaging may have led to a surgical cure. In Group B operations, additional tumor was removed after imaging in 4/30 patients, with additional dissection being avoided in one patient. No surgical cures were achieved (or intended) in these patients. Additional time incurred from set-up and imaging with iMRI averaged 1.3 hours (1.8 hours for patients in Group B).
Conclusion: (1) In select patients with complex meningiomas, iMRI may be useful in confirming resection and avoiding unnecessary dissection. In this series, this applied equally to tumors of the skull base and those above. (2) In most patients with meningiomas, surgical navigation with preoperative imaging can be used without incurring the additional time and other potential limitations of the iMRI environment.

Multimodal imaging agents to combine surgical planning and fluorescent image guidance in sentinel lymph node imaging and tumor targeted applications

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Aims: Fluorescence guidance during surgical interventions is an upcoming technology. Nevertheless, the limited tissue penetration of fluorescent dyes makes it difficult to assess their targeting efficacy and to accurately plan the surgical procedure. Radioactive imaging agents, on the other hand, can provide accurate and quantifiable 3D visualization. We reasoned that combining fluorescent and radioactive imaging approaches is likely to help improve the efficacy of image-guided surgery.
Methods: Multimodal imaging agents that contain both a radioactive and a fluorescent label make it possible to detect exactly the same features with both nuclear and optical imaging techniques. The radioactive component can be used to validate the distribution and provide accurate surgical planning in three dimensions, while the fluorescent component can provide real-time fluorescence image guidance.
Results: By labeling albumin radiocolloids with the fluorescent dye ICG, we are now able to provide optical guidance to the sentinel lymph node as defined using lymphoscintigraphy (current clinical standard) [1]. This technique is already being used in a number of clinical pilots at the NKI-AvL. In addition to nanoparticles, a number of tumor-specific peptides have also been functionalized with a multimodal label [2]. We have shown that for example a multimodal derivative of RGD, an alpha-3-beta-5 targeting peptide, can be used to surgically remove the primary tumor and its metastases. In both applications the fluorescent component allows for accurate ex vivo analysis of the targeting efficacy.
Conclusions: We have demonstrated that multimodal imaging agents have can directly link nuclear medicine based imaging with intraoperative fluorescence guidance in both sentinel lymph node and tumor targeted applications. In both cases, the multimodal approach was superior over the fluorescent approach.

1. Buckle et al. Nanotechnology 2010;21;355101
2. Kuil et al. Bioconjugate Chemistry 2010;21:1709-1719

Intraoperative O-arm confirmation of location during functional neurosurgery

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Aims: Deep brain stimulation has become the treatment of choice for a variety of movement disorders. Targets for implantation of DBS electrodes require accurate localization to ensure efficacy and patient safety. This study aimed to evaluate intraoperative use of the O-arm radiographic imaging system to confirm accurate electrode placement during functional neurosurgery using a frameless stereotactic system.
Methods: A retrospective study was conducted of 27 patients in whom 35 electrodes were placed over one year. Microelectrode recordings were obtained to optimize final positioning of each electrode. For each case, intraoperative 3D scans were obtained with the O-arm and fused to preoperative MRIs. Data from 25 cases were stored on a StealthStation navigation system, and the predicted accuracy and deviation from the planned trajectory were analyzed for each electrode placement.
Results: The average distance of an electrode from the planned trajectory was 1.55 mm (SD: 0.71 mm). The majority of placements required only a single pass. If a second or third pass was necessary (3 and 1 cases, respectively), O-arm imaging was used to determine the actual position of the electrode and the next pass planned accordingly.
Conclusions: Intraoperative O-arm imaging is beneficial for showing deviation from the planned trajectory and confirming electrode placement. Planning, insertion and confirmation can thus be integrated into a single procedure. The system allows detection of brain shift caused by air entry, and visualization of ventricles using improved imaging detectors and software may allow correction of tissue shift in the future. This radiographic approach also permits the use of intraoperative microelectrode recording for final target optimization. More accurate localization helps reduce the number of passes, thereby decreasing operating time and increasing patient safety. Testing is underway to examine if the device can be used for initial imaging registration as well, allowing for a fully integrated system.

Intraoperative dynamic contrast-enhanced T1-weighted MRI differentiates residual glioblastoma from surgically induced changes

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Background and purpose: During intraoperative magnetic resonance imaging (iMRI), gadolinium may accumulate along the resection border, causing difficulty in differentiation between contrast-enhanced residual tumor and surgically induced enhancement. The purpose of the study was to assess intraoperative dynamic contrast-enhanced T1-weighted imaging (DCE-MRI) in the differentiation of residual tumor and surgically induced enhancement.
Method: Six patients diagnosed as high-grade gliomas underwent resection using iMRI guidance. Preoperative and intraoperative DCE-MRI was performed in all patients. The time-intensity curve was generated from every contrast-enhanced region with the

region of interest-based method. Time-intensity curves were compared with preoperative counterparts. Histopathology of the re-resected parts was used as the criterion standard.
Results: All tumors were diagnosed as WHO grade IV. Nine contrast-enhanced regions in 6 patients detected at the first look iMRI were sampled and labeled separately. Four of these were diagnosed as residual tumor and 5 of the 9 were diagnosed as surgically induced enhancement. All time-intensity curves generated from residual tumor and their preoperative counterparts were nearly identical and showed a quickly increasing slope. All time-intensity curves obtained from surgically induced regions were undulating and low in amplitude, compared with those obtained from residual tumors.
Conclusion: Surgically induced enhancement during iMRI in patients with high-grade glioma is not a rare phenomenon along the resection border and DCE-MRI can discriminate surgically induced enhancement from residual tumor.

Session VI: iOI & outcome

Outcome of glioma surgery and iMRI (Invited presentation)

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We began operating with intraopertative magnetic resonance imaging (iMRI) in Argentina in June 2000. We have already operated 173 gliomas of different histological types: 53% were low grade gliomas and 47% were high grade. Twenty-one cases were located in the insular region. We use a 0.23 Tesla open MR system.
Neurosurgeons, as well as radiotherapists and oncologists, all agree that resection of most tumors is the best predictor in the treatment for all gliomas. We also know that a partial removal of a brain glioma barely affects the patient's over-life quality or survival time, just like a stereotactic biopsy. As neurosurgeons, we have the task of extirpating the tumors thoroughly. However, checking the last decade's international records shows that, before the introduction of surgery with iMRI, gross total resection (GTR) was achieved only in a very few cases.
iMRI improves the quality of the surgery and the sharpness of resection. It also increases the possibility of saving important functional areas. The result of all these better safety conditions is fewer complications and many chances for better over-life quality for patients.
On the one hand, resecting a low-grade glioma completely means, in most cases, the cure of the patient, but on the other hand, partial resection assures regrowth and, in many cases, even malignant transformation of the tumor, and the patient may thus lose the only chance to save his or her life, which was the first surgery.
Complete removal of high-grade gliomas improves patients' over-life quality and survival time. In these cases, however, radical surgery is not enough to cure the patients. We are convinced that neurosurgery with iMRI is the sharpest and safest method to extirpate brain gliomas completely, and I think in the near future it will become an essential tool for these kinds of operations.

Challenges in iMRI – ''Spread'' enhancement during glioma surgery (Invited presentation)

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Introduction: Intraoperative MRI (iMRI) has been employed for various indications. While technical issues have been solved, and microsurgery is possible in an iMRI environment, surgery of high-grade gliomas in particular poses a major imaging challenge. While we know that tumors extend beyond the margins of MRI contrast enhancement, this lesion is taken as the activation portion. Subsequently, the surgical result is described by the percentage of the contrast-enhancing lesion removed. Nevertheless, contrast enhancement merely reflects the local breakdown of the blood-brain barrier and does not remain constant. Imaged in various time intervals, the contrast diffuses into the surrounding area. While this is inconsequential in conventional diagnostics, it becomes of major importance in intraoperative MRI.
Methods: In the first 200 patients with contrast-enhancing malignant gliomas we analyzed the time-dependency of contrast enhancement. In all cases initial resection was guided by neuronavigation and augmented by fluorescence microscopy (5ALA). To capture time-dependent contrast enhancement a standard protocol was instituted which includes comparable sequences at specified time intervals.
Results: Contrast enhancement shows non-specific, time-dependent characteristics. Images taken immediately after contrast administration reliably depict tumor extension. However, even within the short time course of our study scans, contrast dilutes and spreads into the surrounding area, yielding ambiguous information.
Conclusions: Contrast enhancement is non-specific and time dependent. Knowledge of this phenomenon, and specific imaging protocols to compensate for this effect during iMRI surgery are required. Furthermore, analysis of this problem emphasizes the non-specific enhancing nature of current contrast agents, highlighting the need for more specific contrast media.

Session VII: iOI in glioma surgery

Combining functional mapping and iMRI for maximizing safe resection of gliomas

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Introduction: Image guided surgical navigation helps in the resection of skull base tumors to a great extent, yet when used for resection of intra-axial brain tumors it has significant limitations, including but not limited to the brain shift that occurs as a result of the pharmacological dehydration and CSF drainage. This problem was overcome by the use of intra-operative imaging, which helped tremendously in maximizing tumor resection through intra-operative identification and subsequent resection of residual lesions. Another technique, cortical mapping under awake conditions using neuroleptanesthesia, helped with access to intra-axial brain tumors through non-eloquent cortex, minimizing post-operative neurological deficits by avoidance of functional cortex and subcortical white matter tracts. We here present our experience in combining the two modalities to minimize post-operative functional deficit by using intra-operative awake functional mapping, and maximize lesion resection by the use of high-field intra-operative MRI.
Method: 243 procedures were performed on 240 patients in the 1.5 Tesla intra-operative MRI (iMRI), and 30 patients were functionally monitored using different neurophysiological modalities. Twelve patients with intra-axial brain lesions in functioning cortex were operated under local anesthesia and cortical mapping

and were followed for periods of 2 months to 3 years. All patients were between 20 and 55 years of age, and the female-to-male ratio was 1.4:1.
Results: Using volumetric measurement, we confirmed resection in excess of 79% in 7 patients (58%), debulking (60–79% resection) in 3 patients (25%), and limited decompression (<59% resection) in another patient (8.3%). A biopsy of a demyelinating lesion was performed for the last patient (8.3%). None of the 12 patients had additional permanent neurological deficit related to the procedure, two had minor temporary deficits, and one had major temporary deficit. Grade III and IV astrocytomas made up 41% of the series, grade II astrocytomas and grade II oligodendrogliomas composed 25%, grade II mixed gliomas made up 17%, grade III–IV mixed gliomas composed 8.3%, and one lesion turned out to be a demyelinating lesion (8.3%).
Conclusion: Whenever feasible, the combination of intraoperative MRI and awake cortical mapping is extremely helpful in maximizing safe resection of intra-axial brain tumors which (as shown in many studies) improves the overall survival of glioma patients. Further studies are needed to obtain robust data to validate these preliminary results, and long-term follow-up is essential to evaluate the impact of maximum-safe resection on long-term survival and functional outcome.

iMRI in combination with neurophysiological monitoring to optimize resection of eloquently located gliomas (Invited presentation)

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Objective: Several methods have been introduced to improve the extent of resection in glioma surgery. However, radical tumor resections must not be attempted at the cost of neurological deterioration. The aim of this study was to assess whether the use of an intraoperative MRI (iMRI) in combination with neurophysiological monitoring (IOM) is suitable for improving tumor resection without endangering neurological function in patients with eloquently located gliomas.
Methods: We analyzed data for all consecutive glioma patients undergoing iMRI-guided surgery in combination with IOM techniques. These included continuous registration of motor and sensory evoked potentials, as well as direct cortical and subcortical stimulation. We evaluated the extent of tumor resection with early postoperative high-field MRI and determined the clinical status of patients 7 days after surgery.
Results: Fifty-four patients were included in this study. In 21 patients (38.9%) iMRI led to additional tumor resection. Radiologically complete resections were achieved in 31 patients (57.4%), while in 12 of these iMRI had depicted residual tumor tissue before resection was continued. Postoperatively, 13 patients (24.1%) showed new or worsening of pre-existing sensorimotor deficits. These were severe in 4 patients (7.4%). There was no correlation between the occurrence of either any new ($P = 0.77$) or severe ($P = 1.0$) sensorimotor deficit and continued resection after intraoperative image acquisition. Likewise, tumor location, histology, and tumor recurrence did not influence complication rate.
Conclusion: The combination of iMRI guidance with multimodal IOM allows for extended resections in glioma surgery without inducing higher rates of neurological deficits, even in patients with eloquently located tumors.

Our experience with glial tumors in an image-guided surgical suite: A consecutive series of 226 surgeries

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Objective: Since April 2008 the image-guided surgical suite has been routinely used for glioma surgery. The suite is directly connected with a 3.0T MR scanner (GE) by a rail-based transfer system (Maquet) and is capable of performing iMRI examinations.
Methods: A consecutive series of 226 surgeries in 201 patients with iMRI is presented. All patients signed informed consent for iMRI examination. The patient's head is fixed in a 3.0T MR-compatible headholder. Surgery may be interrupted according to the neurosurgeon's decision at any moment and iMRI is then performed.
Results: From April 2008 to October 2010 201 glioma patients underwent 226 surgeries (189 resections, 37 stereobiopsies) with iMRI. We have performed a prospective study to evaluate the safety and efficacy of iMRI in this consecutive series. In 99 patients radical resection was intended and was achieved in 80 (80%). Unexpectedly, radical resection was achieved in 9 cases in the group when a preoperative decision was made to perform only partial resection (90 cases). In 89 of 189 cases the tumor was radically resected (MR radicality), i.e., in 47% of all resections. In comparison with our older series, the radicality ratio doubled (from 22% in 2006 to 47% in 2010). The goal of resection was achieved in 167 surgeries; in 22 cases the resection could have been more extensive on retrospective analysis. Mortality in the series was 3.1% (7 patients); the most common cause of death was hematoma (5 cases). Morbidity was 26.5% (60 patients with any kind of complication, including any temporary neurologic deterioration, any wound complication, etc.). Serious clinical deterioration was observed in only 7.5% (17 patients). Permanent MM was thus 10.6%.
Conclusions: Image-guided surgery is valuable for gliomas, being efficient and safe. In our experience the resection radicality increased more than two-fold. The MM rate is slightly higher in this series but is still acceptable.

First experiences with 3D-reconstructed navigated and contrast-enhanced ultrasound in malignant brain tumor

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Objective: Due to the technical capabilities in advanced application of ultrasound and high-resolution real-time viewing, intraoperative ultrasound technology turned out to be a simple tool for brain tumor surgery. However, the sensitivity and specificity of B-mode ultrasound is limited in the detection of tumor remnants, as well as in the differentiation of edema and vascular structures. Therefore, our investigations focused on contrast-enhanced ultrasound and its impact on intraoperative imaging in a 3D-navigated scenario.

Methods: Our preliminary series included five glioma patients. Intraoperatively, a 3D-reconstructed transdural ultrasound was performed with a linear array (Toshiba®) after contrast agent application (SonoVue®) and integrated into the neuronavigation (LOCALITE®).
The ultrasound probe was tracked and calibrated. After resection, another contrast-enhanced US scan was performed to verify tumor remnants. 3D datasets were analyzed in comparison to pre- and postoperative MRI data.
Results: In all cases, uptake of the contrast agent was observed and the tumor margins and configuration could be identified. Real-time integration of the US data into the 3D neuronavigation was possible in all cases. The tumor, as well as other anatomical structures, could be identified in the compare panel with a minimal deviation of up to 2 mm in comparison to the preoperative MRI. Additionally, the contrast uptake revealed a high overlap with contrast-enhanced MRI areas.
Conclusion: The reconstructed 3D contrast-enhanced ultrasound seems to be an additional, useful method for intraoperative visualization of tumor as well as tumor remnants, providing an effective resection control in glioma surgery.

A prospective randomized trial to study the efficacy of low-field iMRI-guided frameless stereotactic biopsies of brain tumors - preliminary results.

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Aim: Application of intraoperative low-field MRI (iMRI) for conducting stereotactic biopsies of brain tumors enables intraoperative verification of the biopsy needle position and an early identification of possible bleeding. In addition, iMRI-guided biopsies seem to generate lower costs compared to biopsy procedures guided by preoperative diagnostic scans. To date, there is no evidence-based information in the literature regarding the safety and effectiveness of iMRI-guided biopsies versus standard stereotactic procedures.
Methods: A pilot group of 21 patients was prospectively randomized by minimization according to demographic and epidemiologic data into an iMRI group (10 patients operated under the guidance of a PoleStar N20 0.15 T iMRI system) and a control group (11 patients who underwent frameless stereotactic biopsy). The comparative analysis of the groups included the following: preparation time, operation time, postoperative complications ratio, and accuracy of histopathological diagnosis. Statistical analysis with a p-value <0.05 was performed.
Results: The iMRI group and the control group did not differ essentially according to gender ($p = 0.57$), age ($p = 0.60$), predicted histopathological findings ($p = 0.97$), localization of pathology ($p = 0.40$), Karnofsky scale ($p = 0.24$) or ASA scale $p = 0.32$). The mean preparation time for surgery was 52 ± 30 min (iMRI) and 36 ± 28 min (control) ($p = 0.24$). The mean operation time was 75 ± 25 min (iMRI) and 59 ± 18 min (control) ($p = 0.12$). Biopsies obtained were suitable for neuropathological studies in 9 cases (90%) from the iMRI group and 8 cases (74%) from the control group ($p = 0.53$). No postoperative complications were noted in either group.
Conclusions: Use of iMRI is comparable in terms of time, safety and effectiveness to standard frameless stereotactic biopsy procedures, but generates lower costs. Thus, it could be considered as a preferred method for conducting stereotactic biopsies of brain tumors.

The value and limitations of 3D intraoperative ultrasound (IOUS) for tumor resection (Invited presentation)

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Intraoperative ultrasound (IOUS) has been used extensively over the years for a variety of neurosurgical procedures. However, only following recent technological advances that enable intraoperative 3D image acquisition and integration into dedicated navigation systems have the full capabilities of IOUS been recognized.
At the Tel Aviv Medical Center we have used the MISON SonoWand IOUS system, which provides 3D US-based images with full navigation capabilities, in over 700 operations, most of them for resection of low- and high-grade intra-axial tumors. The high-resolution images obtained with the system with the built-in new features of instant fusion with pre-operative MR images provide an excellent platform for orientation, adjustment of brain shift, and identification of functional data (e.g., fMRI data, DTI tractography, etc.) and anatomical landmarks. The use of this technology is highly intuitive and fast, with only minutes being needed for updating the images during the operation. However, there are still several shortcomings and limitations associated with the use of this technology. These include the need to plan the position of the patient in a way that allows the surgeon to use IOUS during the operation (after tumor resection, where a water interface is needed for optimal US resolution), the creation of artifacts from debris and hemostatics within the resection cavity, and the possibility of pressure-induced artifacts (from the pressure exerted by the US probe during image acquisition). These issues will be discussed with representative images and video clips to enable critical understanding and assessment of this intraoperative imaging modality.

Session VIII: New horizons in imaging science

The human connectome project (Invited presentation)

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The importance of the organization of the human mind was emphasized by Walter Penfield when he wrote ''Understanding of how the brain functions, to the end that malfunction be corrected, is the most important, and the most neglected, of research adventures today''[1]. Penfield's complaints of this *terra incognita*, written in 1954, still ring true today in that we still do not know how the human mind is constructed, and emphasize the disparity between medical need and basic science knowledge of the connections of the most complex structure known in the universe. Although this disparity was attributed by Penfield to ''neglect'', the microscopic nature of neural connections has made such research highly difficult when probing the intact human brain. The development of new highly detailed imaging techniques such as functional magnetic resonance imaging (fMRI), diffusion tractography imaging (DTI), and magnetoencephalography (MEG) suggest that we may finally have the tools at hand to reveal the connections of the human brain. The map of

these connections between structures within the brain comprises a connection matrix or connectome as defined separately by Drs. Olaf Sporns and Patric Hagmann in 2005 [2, 3], a term partly inspired by the concomitant sequencing of the human genetic code termed the genome. The Human Connectome Project (HCP) has been conceived as a means of comprehensively and accurately mapping the neural pathways that are the basis of brain function. While it is not currently feasible to construct the human connectome at the level of single neurons, mapping the connectivity of anatomically distinct brain regions and inter-regional pathways is now possible, and the goal of the HCP is to build a connection matrix summarizing the macroscopic connectivity of every area of the brain.

This 5-year project is to be carried out in two phases by a consortium of 34 investigators at 9 institutions, with primary data acquisition being conducted at three of these institutions. Phase I of the project (years 1 and 2) will focus on optimization of data acquisition and analysis techniques that are effective for all brain regions. In Phase II (years 3–5) data will be acquired from 1200 healthy adults. Comprehensive mapping of the neural circuitry of the subjects will be accomplished by concomitant advancement in the methodology of noninvasive MRI-based neuroimaging. The project will improve 3T and 7T MR scanners using customized head coils and optimized pulse sequences. High Angular Resolution Diffusion Imaging (HARDI) and diffusion tractography will be used to chart the trajectories of fiber bundles in the white matter and generate maps of structural connectivity between gray matter regions, while Resting-state fMRI (R-fMRI) will provide comprehensive descriptions of functional connectivity between different gray matter regions, based on correlations in the fMRI BOLD signal among functionally interacting regions.

Additional information about brain function will be obtained using task-fMRI and neurophysiological studies consisting of task and resting state MEG in combination with electroencephalography, yielding information about brain function on a millisecond time scale. In parallel with the imaging studies, behavioral testing will be undertaken using a battery of tests to assess sensory, motor, and cognitive function, thereby enabling the identification and analysis of brain circuits associated with particular behavioral features or traits. Finally, the subjects will consist of pairs of identical twins, fraternal twins, and non-twin normal siblings whose genotypes will be explored to detect genome-specific connectivity maps.

It is expected that the project will yield petabytes of information which will be catalogued and made available over the web by a variety of analysis and visualization tools created by the informatics groups associated with the consortium. Results will be made freely available to the scientific community at regular intervals via the ConnectomeDB informatics data management system and the user-friendly Connectome Workbench visualization platform, thereby enabling explorations and analyses of brain circuitry even as data collection continues. It is hoped that the use of these sophisticated network modeling tools will allow anyone with an interest in the area to determine specific connections between areas of subject brains also present on the site. In this way maximal exposure and analysis can be performed on the data accumulated by this $36 million project.

The consortium is expected to yield invaluable information about brain connectivity, and provide a better understanding of its relationship to behavior, along with insight into genetic and environmental factors that contribute to individual differences in brain circuitry. From a clinical standpoint, the project should provide the techniques to reveal how brain circuitry changes during development and aging and how it differs in numerous neurological and psychiatric disorders. It is to be hoped and anticipated, that the *terra incognita* described by Penfield will be transformed into *terra cognito* well travelled by the neurosurgeons of the 21st century.

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Session IX: Pediatrics

100 consecutive pediatric intraoperative high-field MRI brain tumor resections

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Introduction: The application of diagnostic-quality intraoperative Magnetic Resonance Imaging (iMRI), rapidly entering mainstream adult neurosurgery, is now being introduced to pediatric neurosurgery. We have designed a unique IMRIS iMRI suite whose mobile ceiling-mounted 1.5-Tesla Siemens magnet glides from a diagnostic suite to an operative suite. We present our first 100 consecutive iMRI brain tumor cases.

Methods: In February of 2007, Cook Children's Hospital opened the Mr. and Mrs. TL Dodson, Jr. Neurosciences Suite. Although purchase of MRI-compatible anesthesia equipment proved necessary, our safety protocol has allowed use of standard operating equipment, including intraoperative navigation and a mobile operating microscope.

Results: We employed iMRI during 100 tumor extirpations in patients aged 3 months to 21 years (average age 8.4 years). Posterior fossa tumors accounted for 47% of procedures. Low-grade glioma represented 57%. We averaged 1.2 intraoperative scans per procedure. Intraoperative MRI prompted additional tumor resection in 42% of cases. Two tumors (one malignant, one benign) demonstrated regrowth despite gross total resection confirmed by iMRI, necessitating reoperation months later. A few instances of self-limiting cutaneous injury related to positioning have been the only complications.

Conclusion: Intraoperative MRI facilitates aggressive brain tumor resection in infants and children with a low complication rate. Intraoperative MRI during tumor resection surgery has become standard practice in our institution.

Implementation of a mobile 0.15 T iMRI in pediatric neuro-oncology: feasibility and correlation with early postoperative high-field-strength MRI

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Aim: To demonstrate the feasibility of ultra-low-field intraoperative MRI (iMRI) in pediatric neuro-oncology, and the correlation of iMRI and early postoperative MRI (EPMRI).

Methods: Between 2005 and 2010 a total of 11 iMRI-guided craniotomies for brain tumor resection were performed in 9 children between one month and 17 years old. The iMRI set-up consists of a 0.15 Tesla magnet (PoleStar N20) and a mobile Faraday cage (a so-called StarShield). A pediatric horseshoe headrest is available if the neurosurgeon decides not to use head clamping. The incision was planned on non-contrast-enhanced images. To determine the amount of tumor resection, imaging

was repeated and additional contrast-enhanced images were acquired before closure after administration of gadopentetate dimeglumine at 0.1 mmol/kg.
Results: Patient positioning was relatively straightforward in all positions (supra- as well as infratentorial) as well as in all age categories (babies, infants, toddlers). Whenever iMRI images were convincing of gross total resection, this was confirmed by EPMRI. However, in those two cases where we were not sure about the iMRI interpretation, EPMRI demonstrated residual tumor. Extra set-up time now typically takes approximately 30–45 minutes, and preparing for an intraoperative scan approximately 10 minutes. We did not encounter any serious intraoperative adverse event nor any postoperative infection related to the use of the iMRI system. However, two children complained of transient shoulder pain, including one child with a very mild, transient proximal brachial paresis.
Conclusion: iMRI-guided resection of intrinsic brain tumors using the PoleStar N20 is feasible in infants of all ages with supra- as well as infratentorial tumors. Correlation between iMRI and EPMRI is good, provided iMR image quality is optimal and interpretation is carefully done by someone sufficiently familiar with the system.

Combined iMRI and navigated endoscopy in children with multiloculated hydrocephalus and complex cysts: a series-based feasibility study

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Objective: Neuroendoscopy is an important tool in the treatment of hydrocephalus; however, in cases of distorted anatomy and multiloculated cysts, endoscopy alone might be problematic as regards appropriate orientation and re-evaluation of brain shift. The aim of this project was to assess the feasibility and efficacy of intraoperative MRI (iMRI) guided, navigated neuroendoscopy in infants.
Patients and methods: Five infants (ages 6–14 months) were operated for multicystic hydrocephalus presenting with shunt malfunction (4 patients) and a quadrigeminal fetal arachnoid cyst (1 patient). For all infants iMRI (0.12-Tesla PoleStar N-10 / 0.15-Tesla PoleStar N-20) was combined with navigated endoscopy. E-steady, T1 and T2 sequences were used (24 sec to 3.5 min).
Results: The iMRI system provided clear images that correlated with the endoscopic appearance of the cystic membranes in all patients, and was helpful in determining trajectories and redefining targets. The intraoperative MR images documented brain shift and change in CSF spaces during surgery. There were no intraoperative complications or technical difficulties with visualization. No infection or any other immediate postoperative complication occurred. Patients were followed up for 6 months to 7 years. The infant with the quadrigeminal cyst is still shunt-free, and the patients with multicystic HCP have 1–2 shunts each. In children with endoscopic-iMRI guided surgery, shunt catheter positioning was verified in the postoperative imaging.
Conclusions: The combined advantages of navigated endoscopy and iMRI may complement each other in specific indications and offer an advanced adjunct to complicated procedures, where intraoperative changes alter the spatial distribution. In such cases, targets and trajectories need to be redefined. iMRI enabled transformation of a blind conventional stereotactic procedure into a visually controlled procedure by updating and redefining new targets during surgery, allowed accurate navigation of the endoscope, and minimized the number of compartments in all patients. No complications related to the use of iMRI occurred.

Use of the PoleStar 0.15T iMRI in pediatric cases. The Sheba Medical Center experience

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Aims: To evaluate the efficacy of the low field Polestar N10, N20 and N30 iMRI in pediatric cases at the Sheba medical center.
Methods: Since 2001, 46 pediatric neurosurgical procedures have been done, intially using the Polestar N-10, which was upgraded to the N-20 system in 2003, and the N30 system has been in use since 2009. Forty-one patients (18 females, 23 males) underwent 46 procedures. Mean age was 13 years. Thirty-one patients underwent tumor resection with the following pathologies: pilocytic astrocytoma, Grade II astrocytoma, high-grade glioma, oligodendroglioma, pituitary adenoma (2 GH secreting, 1 prolactinoma), ganglioglioma, central neurocytoma, choroid plexus papilloma, endoscopic cyst drainage for craniopharyngioma, DNET, ependymoma, medulloblastoma, PNET, meningioangiomatosis, metastasis. The remaining non-tumor surgery included cavernous angiomas, AVM, shunt placement, and DBS electrode placement attempt.
Results: For brain tumor surgery, in 19 cases (61%), the surgeon's assessment was completion of tumor removal after a single resection control scan. In 12 cases (39%), residual tumor was suspected and further tumor was removed. One case required resection after a second resection control scan, and in one case 3 scans were done before terminating surgery. All low-grade tumors except 2 cases of hypothalamic glioma and one case of cerebellar ganalioglioma remained tumor-free on follow-up diagnostic scans. Complications included a post-operative brain abscess in 1 case and a severe subarachnoid and intraventricular hemorrhage in a case of a GH-secreting adenoma. This was detected during transsphenoidal surgery in a resection control scan, and surgery was aborted.
Discussion: The Polestar low-field iMRI is an important tool in selected cases to achieve more extensive resection when indicated. Our observation is that it enables higher confidence in achieving the goal of surgery.

Session X: Intraoperative MRI techniques

Improved head holder for increased stability

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Introduction: Image guided procedures depend significantly on the firmness of the patient's head immobilization. Once registered, any movement of the patient's head in the head holder leads to navigation inaccuracies, and the patient registration has to be readjusted.
Objectives: During surgery, when the craniotomy is carried out, we experienced an elevational head offset. As a result, the navigation accuracy decreased, which is a significantly disorienting situation. We realized that the head shift was because of looseness in the double pin carrier of the BrainSUITE® Noras head holder. To overcome this weakness and provide redress for neuronavigation inconsistencies, a consolidator of the double fixation pin carrier has been developed by the Noras Company following our comments and recommendations. This

consolidator helps avoid the rotational movement of the double pin carrier, leading to the elevational offset of the patient's head.
Conclusion: In the continual attempt to further improve the accuracy of image guided procedures, by preventing any movement of the patient's head, an improved version of the Noras head holder was designed to avoid an undesired elevational head movement. We report here the clinical use of this improved head holder.

Feasibility of performing iMRI-guided microsurgery in the semi-sitting position (Invited presentation)

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Background: Intraoperative MRI (iMRI) has emerged as a reliable and useful tool in intracranial brain tumor surgery. Performing iMRI-guided procedures seemed incompatible with semi-sitting patient positioning. Therefore, we conducted a feasibility study.
Methods: An iMRI-guided craniotomy and tumor resection was performed in a patient with a recurrent glioblastoma in the occipital lobe extending to the corpus callosum, employing a mobile 0.15 Tesla intraoperative MRI system. The intraoperative set-up and imaging protocol was tested and described previously. All safety precautions routinely used in semi-sitting craniotomy were also applied.
Results: Patient positioning as well as preoperative and intraoperative image acquisition could be accomplished. Tumor resection was performed in a standard fashion. Intraoperative imaging displayed complete resection of enhancing tissue, which was later confirmed by early postoperative high-field MRI. Following our established protocol of patient monitoring, no complications or adverse events were noted.
Conclusion: Intraoperative MRI-guided brain tumor resection is feasible in combination with semi-sitting patient positioning. However, special safety precautions must be followed.

Application of intraoperative high-field MRI and neuronavigation in the surgical treatment of neoplasms of the posterior fossa

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Aims: Anatomical and technical characteristics of positioning, surgery and imaging in the neurosurgical treatment of posterior fossa lesions require particular variations of intraoperative MRI (iMRI) and neuronavigation (NN). The authors summarize their experience using this technology and discuss its impact on the course of surgery.
Methods: Retrospective analysis of 7 pediatric and 6 adult patients (7 male, 6 female, mean age 29 years) treated at a single institution between 2009 and 2010. The patients had various pathologies including pilocytic (3) and anaplastic (1) astrocytoma, glioblastoma (1), ependymoma (1), medulloblastoma (1), meningeoma (1), epidermoid (1), hemangioblastoma (1), cavernoma (1) and inflammatory disease (2). All surgical procedures were performed in prone position under microscope-based NN. The extent of resection was evaluated on 1.5T iMRI. iMRI findings were correlated with histopathologic studies.
Results: Registration of NN was accurate in all cases. NN was very helpful in tailoring the surgical approach and establishing the surgical trajectory. However, the drainage of cerebrospinal fluid during surgery and the opening of cystic tumor compartments led to significant brainshift-related loss of accuracy over time. We achieved gross total resection (10), subtotal resection (2) and performed one biopsy. iMRI was performed once in 12 patients and twice in one patient with excellent image quality. In four of these patients, remnant tumor was depicted and led to further surgery after automated re-registration of NN. Histopathologic studies confirmed these iMRI findings.
Conclusions: The application of iMRI for lesions of the posterior fossa effectively tracks the extent of tumor resection and the anatomical changes during surgery. Its potential to optimize the resection of tumors is greatest when it is coupled with integrated NN capabilities.

Anaesthetic considerations of the first 52 neurosurgical operations undertaken in the iMRI theatre at the National Hospital for Neurology and Neurosurgery (London)

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Introduction: The first interventional MRI (iMRI) theatre in the UK opened at NHNN in April 2009. Multiple challenges were involved in establishing this service. A multi-disciplinary approach, including neuroanaesthetists, neurosurgeons, radiologists and radiographers was required to ensure safety for patients and staff. We evaluated the anaesthetic-related issues of the cases so far performed in the iMRI.
Methods: Surgical cases conducted in the iMRI suite were identified from the theatre register and the case notes were retrospectively reviewed. Data collected included the indication for surgery, case duration, anaesthetic duration, number of intra-operative scans, intra-operative temperature, and any reported complications or critical incidents.
Results: Fifty-two iMRI cases have been performed in 17 months. Indications included supratentorial tumour resection and epilepsy surgery. Mean case duration is 5 hours, 27 minutes for tumour resection, and 9 hours 25 minutes for epilepsy surgery. There have been no serious safety incidents. Five patients had pressure sores related to the operating table design and length of procedure. Hypothermia (temperature <360°C) was a consideration in cases with duration of less than 3 hours, and 2 cases of hyperthermia (temperature >37.50°C) were reported in cases lasting more than 6 hours. Mean time to attain normothermia (36 to 37.50°C) intra-operatively was 4 hours.
Conclusions: Case durations are long, mainly due to surgical times with additional scanning times. The iMRI is an unusual surgical environment and extra care is required in handling ferromagnetic equipment. Careful planning (mock runs, safety training, pocket-less theatre scrubs) have prevented serious incidents, but continued vigilance is required due to the number of staff involved. The long procedure times require the use of urinary catheters, careful patient positioning to minimise pressure sores, and accurate temperature control to prevent hyperthermia.
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Fully functional MR compatible flexible operation table solves neurosurgeon's dilemma using intraoperative MR imaging

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Today, intra-operative MR imaging is widely used in the neurosurgical field. We can now operate a patient near or in the MR magnet and have high-resolution intra-operative MR images. However, neurosurgeons feel some dilemma over using the current MR-compatible operation table, which cannot bend during the surgical procedure. Currently, MR-compatible operation tables generally have an inflexible flat tabletop, which exerts a bad influence on the surgical procedure, such as insufficient cerebrospinal fluid and venous drainage, and a narrow microsurgical field. In February 2006, our hospital officially opened the Magnetic Resonance / X-ray / Operation (MRXO) suite, which is the world's first radiology and neurosurgical interventional suite. This interventional surgical suite represents a major advance in the field of neurosurgery, and details of the MRXO suite have been reported previously.
We have developed a specially designed fully functional MR-compatible flexible operation table for MRXO which can change the patient position during surgery. This flexible operation table attends to surgeons' wants during the surgery. In this paper, the authors report the details of the newly developed fully functional MR-compatible flexible operation table and discuss its advantages.

Estimating a safe margin around Meyer's loop to account for brain shift during anterior temporal lobe resection

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Aim: Anterior temporal lobe resection is an established and effective treatment for medial temporal lobe epilepsy in patients who do not respond to antiepileptic medication [1]. This treatment is often complicated by visual field defects due to damage to Meyer's loop [2]. Diffusion tensor tractography can be used to identify Meyer's loop [3], but the accuracy of such outlines in surgical navigation is limited by intra-operative brain shift [4]. Here we describe an approach to establishing a locally applicable safety margin to account for this displacement.
Method: Volume images were acquired from 9 consecutive temporal lobe resection patients (T1-weighted 3D FLASH, $1.1 \times 1.1 \times 1.3$ mm voxels) pre-operatively and intra-operatively after temporal pole resection. Rigid registration was used to pre-align these based on the contralateral side only [5]. Free-form registration was then performed on the brain tissue with B-spline control points on a 5-mm grid [6, 7]. Deformation was measured at the anterior limit of the temporal horn (TH) of the lateral ventricle (near Meyer's loop [3]) and, for comparison, at the posterior commissure (PC).
Results: At the TH, a maximum RMS deformation of 6.1 mm was observed across all cases (median 2.7 mm, inter-quartile range 1.0–4.8 mm). At the PC, this maximum deformation was 2.3 mm (median 1.1 mm, inter-quartile range 0.8–2.1 mm).
Conclusions: These results suggest an uncertainty due to brain shift of 6 mm around Meyer's loop with respect to pre-operative imaging, for this procedure, as performed at this hospital. A similar approach could be used to establish local safety margins for other procedures and sites.

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Intraoperative indocyanine green-videoangiography (ICG-VA) in intracranial aneurysm surgery

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Objective: To assess the feasibility and potential utility of the intraoperative ICG-VA in assessment of the unexpected residual aneurysm and major cerebral artery occlusion or stenosis after cerebral aneurysm surgery.
Methods: Fifteen consecutive patients with anterior circulation aneurysms who underwent craniotomy and clipping of the aneurysms were included in this study. Intraoperative ICG-VA was performed in all cases after exposure of the aneurysm and the branches in the vicinity of the aneurysm or the parent vessel before clipping of the aneurysm and postclipping after the surgeon was satisfied that the aneurysm neck was completely obliterated. We analyzed the ICG images with regards to residual aneurysm or major arterial occlusion or stenosis and compared them with postoperative digital subtraction angiography (DSA) that served as a control.
Results: In 4 patients there was small residual neck detected by intraoperative ICG, which was immediately corrected by clip readjustment for immediate correction and replacement, and this was confirmed by the postoperative DSA. No major arterial occlusion or stenosis was detected in ICG or postoperative DSA images.
Conclusions: ICG-VA is a simple, fast method for blood flow assessment that provides real-time information about the blood flow in vessels of different sizes as well as the obliteration of the aneurysm. It may be a useful adjunct to improve the quality of intracranial aneurysm surgery.

Intrinsic cerebral tumors that favor gross total resection with iMRI: A case series

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Aims: Intraoperative MRI has documented advantages for improving the resection of intracranial tumors. However, most studies suggest that gross total resection, as opposed to subtotal debulking, favors a longer disease-free interval, particularly in malignant gliomas. This study examines a small series to

determine which pathologic factors improve the likelihood of achieving gross total resection when using a modern intraoperative MRI system.
Methods: All craniotomies performed by the primary authors between 6/06 and 9/10 with the intent to debulk an intrinsic tumor were retrospectively reviewed. Surgeries were performed in an IMRIS suite utilizing a Brainlab frameless navigation system. After primary debulking, an intraoperative MRI was obtained. Secondary resections were performed if clinically feasible and residual tumor was detected. In most cases, the navigation system was registered with new fiducials to better localize accessible tumor. Case characteristics including pathology, number of resections, extent of disease, and outcomes were collected.
Results: Thirty-one surgeries were performed in the study period. Of the 16 that had only primary resection, nine had radiographic gross total resection. These included four glioblastoma multiformes (GBMs) and five metastatic tumors. Of the 15 that underwent secondary resection based on information from the intraoperative MRI, 11 achieved gross total resection. These included eight GBMs, one malignant ependymoma, and two metastatic tumors. Of 11 surgeries that had subtotal debulking regardless of the number of resections, ten were metastatic tumors.
Conclusions: Information from intraoperative imaging changed surgical planning in nearly half of operated cases. In that subset, the tumor types most likely to achieve gross total resection were primary neoplasms generally and GBMs specifically. Metastatic tumors tended to benefit least from intraoperative imaging since they were often completely resected primarily or the extent of disease precluded complete surgical removal.

Session XI: Alternative iOI methods

Intraoperative imaging: If I could as I would

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Intraoperative imaging is considered one of the major technologies for state-of-the-art operating theaters in the future. Although the clinical value is widely recognized, the definition of intraoperative imaging potentially includes a variety of imaging techniques with different advantages and disadvantages. Establishing an OR with intraoperative imaging is often limited by financial or infrastructural restrictions. Planning intraoperative imaging without these limitations and considering only potential clinical needs, an operative area with several ORs rather than one OR with intraoperative imaging is required. Based on the imaging modalities with the best resolution for the different tissues and organs, the concept includes three separate and independent ORs that are equipped with one of the major imaging modalities, e.g., 3-T MRI, CT and digital subtraction angiography and navigation technology integrated with the respective imaging modality. The ORs are supplemented with microscope-integrated fluorescence imaging technologies (5-ALA and ICG), intraoperative ultrasound, flat panel fluoroscopy, and advanced intraoperative monitoring and mapping techniques. Such an area can only be realized when these ORs are being used interdisciplinarily by heart surgeons and cardiologists, along with abdominal, orthopedic, trauma, ENT and maxillofacial surgeons. This could trigger a major change in the philosophy of surgery for a large hospital by providing the infrastructure that is required to shift the quality check from the postoperative to the intraoperative period, where the surgeon can optimize the result of surgery by having an intraoperative image.

Intraoperative imaging on the cellular level - what is coming next? (Invited presentation)

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Introduction: Recently, we have shown intraoperatively that optical coherence tomography
(OCT) is capable of visualizing tumor remnants. However, cellular imaging is not realizable with OCT, which stimulated the search for other imaging methods which allow identification of single tumor cells in the *in vivo* environment. Beyond this, visualizing effective eradication of tumor cells by means other than surgery would be a desirable goal to enhance the amount of tumor resection.
Methods: We evaluated the role of multiphoton microscopy and quantum dots (QD) as fluorescent nanoparticles for identification of tumor cells and of superparamagnetic iron oxide nanoparticles (SPIONs) as potential vehicles for drug delivery.
Results: Multiphoton microscopy allows visualization of single glioma cells. By color-coding of the fluorescence lifetimes, which are different for glioma and normal brain tissue, automated tumor identification is realizable and differentiation of grade 2 to grade 4 gliomas is possible. By staining the QD surface with EGF and monoclonal antibodies directed against extracellular portions of the erbB1 and PDGF receptors, identification of high-grade glioma and, for the first time, even low-grade glioma is achieved. QDs-EGF was internalized by glioma cells which expressed intact erbB1 receptors, whereas QDs coupled to specific monoclonal antibodies remained on the cellular surface. In contrast, cultured glioma cells and human glioma biopsies could be induced to internalize all bound SPIONs by simple magnetic stimulation.
Conclusion: We have shown that identification of single tumor cells is possible by two imaging technologies: multiphoton microscopy and QD. This possibly offers the chance to enhance the radicality of glioma resection. SPIONs could be promising vehicles for drug delivery because of their small size, enabling diffusion, their fast coupling to target cells, and their easy incorporation by magnetic stimulation.

Fluorescence-guided surgery for malignant glioma: A review on aminolevulinic acid induced protoporphyrin IX photodynamic diagnostic in brain tumors

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Gross total resection, though proven to be effective, is often hindered by the notoriously challenging differentiation between malignant glioma and the surrounding edematous brain when using standard white light microscopy. Intraoperative imaging or neuronavigation by preoperative datasets deliver inconsistent results as they often fail to demonstrate tumor or resection borders reliably. With the introduction of 5-aminolevulinic acid (5-ALA, Gliolan®) fluorescence microscopy, neurosurgeons command a highly specific biological tumor marker for malignant glioma resection to help distinguish the vital tumor tissue from normal brain and improve the extent of tumor removal.

Current applications of intraoperative ultrasound and future perspectives (Invited presentation)

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This presentation will focus on current clinical usage of intraoperative ultrasound in various cases and using various techniques. Experiences with real-time 3D ultrasound and navigated 3D ultrasound, as well as recent advances in high-frequency ultrasound, will be demonstrated with clinical cases. In particular, the high-frequency ultrasound probe with frequencies up to 15 MHz enables the surgeon to differentiate structures in the submilimeter range. Several clinical examples of malignant and benign glioma resections, as well as anatomical studies, will be demonstrated. High-frequency ultrasound has the potential to enhance resection control. The use of ioUS in pediatric cases with different examples will be presented, as well as enhanced use in spinal cavernoma cases (series). Here, intraoperative resection control can be demonstrated in special cases. Finally, new developments in ultrasound probes will be discussed. Wireless probes and automatic, customized settings, as well as neurosurgical customized machines, could significantly improve daily work and patient outcome.

Session XII: Intraoperative imaging in skull base surgery

Intraoperative CT in endoscopic skull base surgery (Invited presentation)

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Objective: Improvement in surgical techniques allocates enormous development to transcranial and transnasal neurosurgery, treating more complicated diseases through limited minimally invasive approaches. Limited approaches may offer reduced approach-related traumatization, but they can cause limited orientation in the deep-seated surgical field. To allow adequate intraoperative exposure, the optical properties of surgical microscopes can be effectively supplemented by the intraoperative use of endoscopes. In addition, the intraoperative use of navigation systems and real-time imaging, e.g., ultrasound, intraoperative CT (iCT) and MRI, may be helpful if the limited cranial opening leads to a confusing and purely overviewed situation.
Methods: In this report, we have overviewed our preliminary experience in intraoperative use of iCT in transcranial and transnasal endoscopic skull base surgery. During a one-year period between December 2009 and November 2010, we used iCT during 102 consecutive neuroendoscopic operations. There were 90 transcranial and 12 transnasal operations. The integrated CT navigation tool (BrainSUITE iCT, BrainLAB, Feldkirchen, Germany) was used for registration of the navigation device, controlling tumor removal and excluding operative complications.
Results: The intraoperative use of CT allowed precise registration of the navigation device. During our learning curve, technical pitfalls occurred in 7 cases, thus making optical registration necessary. iCT allowed safe intraoperative control of tumor resection; in three cases, iCT assisted exact localization of endoscopically presumed residual tumor. In one case of a cystic lesion with massive intraoperative shifting, re-registration of the navigation tool was mandatory for safe intraoperative orientation. In one case, severe epidural hematoma could be detected during surgery, thus making emergency evacuation possible.
Conclusion: The endoscopic visualization allowed exquisite intraoperative anatomical orientation, increased light intensity in the deep-seated surgical field with an extended viewing angle, and clear depiction of surgical details in close-up position. With additional use of iCT, the tumor removal could be effectively controlled, especially in hidden parts of the surgical field.

Perspective of iMRI in pituitary surgery

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Intra-operative MRI is currently widely used as a method for immediate evaluation of tumor resection. One of the apparent indications for the use of iMRI is pituitary tumor surgery. Although the extent of residual non-functioning pituitary tumor does not reflect linearly on the rate of tumor recurrence, the aim of surgery is complete resection, if possible. In most of the series reporting on iMRI in pituitary surgery, unexpected residual tumor was found by iMRI in 15–35% of the cases. Further resection led to complete removal in 18–22% of the cases. When analyzing these case series, a picture of the indication for use of iMRI is created. It is clear that for microadenomas and for small and midline macroadenomas application of iMRI is a luxury. In contrast, iMRI is strongly indicated in large macroadenomas with supra- and parasellar extensions, giant adenomas that require transsphenoidal and transcranial approaches, recurrent tumors, surgery for reduction of tumor to fit radiosurgery, transsphenoidal drainage of arachnoid cysts, and craniopharyngioma. Introduction of bone wax, gauze soaked with Gadolinium or a suction tube in the tumor cavity improved the determination of the resection margin. It was demonstrated that the reliability of intra-operative imaging (high- and low-field MRI) as compared with early post-operative or late (3 month) post-operative diagnostic MRI imaging was very high, with a sensitivity (true negative rate) of 98–100% and specificity (true positive rate) of 88%. Like other techniques in neurosurgery, iMRI should be used according to the surgical demand, i.e., to obtain optimal surgical results taking into consideration the availability of the technique,operative time, cost and legal aspects. The indications might be broadened when surgery is performed by an inexperienced surgeon.

Application of iMRI in endoscopic procedures in non-pituitary skull base lesions

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Objective: To present our experience with intraoperative MRI (iMRI) application during endoscopic endonasal resections of nonpituitary skull base lesions.

Methods: In the period from 18 April 2008 to 18 April 2010, 36 endoscopic endonasal procedures were performed for non-pituitary adenoma related lesions. The pathologies treated were craniopharyngeoma (6 cases), postoperative CSF leak (5), meningioma (4), dermoid (4), sellar cysts (4), abscess (3), skull base carcinoma (2), chondrosarcoma (2), spontaneous CSF leak (2), esthesioneuroblastoma (1), intraorbital cavernoma (1), clival lesion (1), pseudoxanthoma (1), post-op hematoma (1), and sinonasal carcinoma (1). In 26 cases a resection was performed, in 10 cases only a biopsy or treatment for CSF leak.
Results: In 16 cases radical resection was intended. iMRI confirmed radical resection in 88% of cases. In 5% of cases iMRI showed residuum of the tumor which was not resected after iMRI, and in 11% of cases iMRI showed residuum of the tumor which was resected after iMRI. In 10 cases partial resection was intended. In 60% of these cases further resection was perfomed after iMRI. There was neurologic morbidity, no postoperative seizures. Postoperative diabetes insipidus was observed in 2 cases. Postoperative CSF leak (5 cases) was the most frequent complication.
Conclusions: iMRI seems to be valuable and safe in resection procedures for non-pituitary skull base lesions.

The outcome of ultra-low-field iMRI-assisted transsphenoidal surgery in a series of 108 consecutive patients with hormonally inactive pituitary adenomas

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Background: Pituitary adenomas (PA) belong to the most frequent primary intracranial neoplasms with an annual incidence up to 8.2 per 100,000. Non-functioning pituitary adenomas (NFPA) constitute 30% of those cases. Symptoms of NFPA include headache, visual deficits and secondary pituitary insufficiency. The treatment of choice is surgery, and radical surgery in NFPA is important to avoid reoperations and recurrent tumor.
Objective: The aim of this study was to analyze the impact of intraoperative magnetic resonance imaging using a PoleStarTM N20 (0.15 Tesla) on the extent of tumor resection and the avoidance of reoperations.
Methods: A series of 109 consecutive cases receiving transsphenoidal iMRI-guided surgery (PoleStarTM N20) between September 2005 and November 2009 for NFPA was analyzed. General patient data, time of surgery and hospital stay, endocrinological parameters, neurological examinations, frequency of reoperations and pre-/post- and intraoperative imaging were evaluated.
Results: One hundred and eight patients with NFPA underwent 109 transsphenoidal surgeries for pituitary adenomas. There were 21 patients with previous pituitary surgery, and in 42 cases the tumor showed invasion into the cavernous sinus. Intraoperatively there was additional tumor removal due to iMRI findings in 46 cases. Three months after surgery, 71 of 94 patients considered tumor free at the end of surgery remained tumor-remnant-free. During median follow-up of 36 months 7 patients needed reoperation because of progressive tumor remnant.
Conclusions: This study shows that iMRI guided transsphenoidal surgery for NFPA is an effective treatment modality. Ultra low-field iMRI provides adequate information regarding tumor removal, and detection of tumor remnant led to an increase in tumor-remnant-free patients and a decrease in the frequency of reoperations during follow-up. Furthermore, the use of iMRI seems to increase the number of giant adenomas accessible through a transsphenoidal approach.

Session XIII: Future of iMRI

Establishment of iMRI database

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Introduction: iMRI is used to improve tumor resections and other procedures. Outcomes analysis based on prospectively acquired data is needed to assess the impact of iMRI.
Method: A prospective iMRI database has been established of all patients undergoing surgery using a movable 1.5 T iMRI, including demographics, tumor dimensions, symptoms, types of procedures, technologies utilized (endoscope, laser, surgical navigation, cortical mapping), clinical and pathological diagnoses, time to perform components of procedures (set-up, surgery, MRI acquisition), iMRI techniques, room utilization, duration of hospitalization, impact of iMRI on extent of resection, infections and other complications, neurological status and survival, additional treatments including surgeries, radiation, chemotherapies, and hormonal therapies. In parallel, data is being collected for patients being treated for brain tumors with or without iMRI. Assessments are made of utilization of iMRI rooms for non-iMRI cases.
Results: Over 350 iMRI cases, and over 400 non-iMRI cases performed in two operating rooms equipped with a movable MRI have been entered into the databases for analysis. Furthermore, the brain tumor component of our databases has accumulated over 2200 brain tumor cases done with or without the iMRI over the past decade at our institution. The iMRI database in particular includes over 130 craniotomies for gliomas, over 100 endoscopic transsphenoidal resections for pituitary adenomas, and other craniotomies for other tumors, non-neoplastic conditions such as epilepsy and infection and Chiari malformations, and for placement of catheters and drainage of cysts. Plans are underway to expand the iMRI database to a web-based multicenter format for more expansive collection of data.
Conclusion: Establishment of a prospective database has enabled accurate data collection for analysis of the impact upon outcome of iMRI on tumor resections and other neurosurgical procedures, and to compare these outcomes to those of procedures performed without the use of iMRI.

Surgical audit of iMRI usefulness in brain tumor surgery – an ongoing prospective study

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Objective: Intra-operative MRI has been in use in neurosurgery for a number of years. We have conducted this study to analyse the impact of intra-operative MRI on brain tumour surgery and surgeons' view of its usefulness.
Method: We collected prospective data of all patients with brain tumours operated in the iMRI suite during the period from April 2010 to October 2010. Operating surgeons were asked to complete a questionnaire before, during and after surgery. Questions were asked about their experience in the use of iMRI and the impact of iMRI on their surgical plans. Volumetric analysis of pre-operative, intra-operative and post-operative tumour volume was carried out using BrainLab software.

These findings were correlated with the surgeons' visual assessment of patients' scans.
Results: A total of 18 patients were operated in the IMRI suite during this period. All patients had pre-operative T1/T2 and BrainLab Volume images either on the day of surgery or a few days prior. Twelve patients were operated in the IMRI suite to confirm complete resection of brain tumours; a further 6 were operated to avoid post-operative neurological deficits. Surgical goals were achieved in 84% patients. Complete resection was achieved in 90% of cases, which was confirmed on intra-operative MRI scans. In 72% of cases IMRI influenced surgeons to modify their surgical planning. In 74% of cases BrainLlab residual tumour volume was more than the surgeons' visual assessment of residual brain tumour. Only two patients had post-operative neurological deficits (limb weakness, visual defects) which improved with time.
Conclusion: IMRI is a useful tool in brain tumour surgery if proper preoperative selection and planning is carried out.

Optimal design for an iMRI-guided neurosurgical suite

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Objective: To determine the optimal design for an intraoperative magnetic resonance imaging (iMRI)-guided surgical suite.
Materials and methods: The ideal magnet strength to perform iMRI-guided neurosurgery remains unclear, with existing units ranging from 0.12 Tesla (T) to 3 T. It is also uncertain whether the iMRI should be stationary or mobile. Most iMRI systems are currently used for tumor biopsy or resection, although some use them to treat spinal and movement disorders. Combining iMRI with PET or angiography may allow for molecular imaging and a multimodal approach to treating vascular disorders.
Results: We have designed three iMRI neurosurgical suites, incorporating changes leading to improved patient care. The first 1.5T iMRI suite (1996) allowed for brain biopsies with MRI compatible instruments at the far end and ferromagnetic instruments on the near side for craniotomies. The second iMRI suite (2004) held a 3T magnet and enhanced surgical throughput since table rotation and instrument removal were not required before imaging. The last suite design (2010, pending) has three rooms with the 3T MR scanner centrally located with surgical and angiography suites on either side. Surgery is possible simultaneously in all rooms. Routine diagnostic imaging can be performed until the surgical patients require their intraoperative imaging. The last design allows for patients with vascular diseases to undergo angiography, diffusion and perfusion weighted imaging, MR angiography, and MR venography.
Conclusions: Because of the increasing number of units becoming operational since 1994, intraoperative MRI is now recognized as a useful adjunct by neurosurgeons that can enhance surgical outcomes and reduce the length of stay and medical costs.