Abstracts for IOIS 2017 in Hanover Germany

Editorial Remark

There are differences between program and abstract book. Abstracts from the same group with overlapping methods were merged into single lectures. However, the abstracts were accepted on their own merit, subsequently all accepted abstracts are published here as submitted.

For the Program committee

A. Nabavi,

Brain Tumor Resection: Measuring the Extent

AN Jha, R Bucholz, G Barbagallo

Glioma Surgery – the spector of gross total resection

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Glioma Surgery with or without Intraoperative MRI: Retrospective Analysis of a Single Surgeon Experience

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Introduction
The goal of surgery for brain gliomas is to maximize the extent of tumor resection avoiding postoperative functional impairment. Intraoperative-magnetic resonance imaging (Io-MRI) has emerged as a safe and effective tool to guide glioma resection.

Methods
104 patients suffering from brain glioma who underwent craniotomy for tumor resection at "Sant'Andrea" and "Santa Maria Goretti" Hospitals of the "Sapienza" University of Rome were retrospectively evaluated. We compared a subgroup of 62 patients operated on without Io-MRI to a second subgroup of 42 patients who underwent surgery with the aid of Io-MRI. Volumetric analyses of the Extent of Resection (EOR) were performed using a gadolinium enhanced T1-weighted imaging for tumors showing contrast enhancement and T2-weighted imaging for non-enhancing tumors. All the surgical procedures were performed by a single surgeon (the senior author).

Results
Both for enhancing and non-enhancing gliomas, the average EOR increased in patients operated on with Io-MRI. The secondary endpoint of the present study was the rate of progression free survival (PFS): in patients operated on for high grade gliomas (III-IV), an increase in PFS was observed in patients who underwent further surgery for tumor residual detected by Io-MRI.

Conclusion
1.5 Tesla Intraoperative MRI is a safe and effective technique, and its use optimizes significantly both the extent of glioma resection and the survival of the patients.

Keywords: MRI, glioma

Smart Cyber Operating Theater(SCOT) : How to integrate MRI into a multimodal information environment

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Background: Modern surgical procedures need many different medical devices that occupy the space of an operation room and might cause surgical incidents and accidents because of difficulty in management. In addition, each device functions as stand-alone and we could not realize data integration among different equipment, thus unable to analyze causal relations and to navigate with consolidated data. To overcome these problems, we are currently developing an integrated operation room called “Smart Cyber Operation Theater (SCOT)” to improve safety and effectiveness of treatment by packaging basic devices and networking of the operating room in conjunction with a decision-making guide, based on intraoperative MRI (iMRI).
Material and methods: SCOT will be comprised of an intelligent operating room for performing information-guided surgery, that has greatly progressed as the basic package, with the addition of intraoperative diagnostic imaging devices and modules for any surgical department, as well as online device system for integrating time synchronization data. In this project, a middleware industrial tool called Open Resource interface for the Network (ORiN) is used as interface to link the applications and the devices that are connected to the system. An advanced version of SCOT, called “Hyper SCOT,” consists of networked surgical equipment (surgical navigation, iMRI, neurophysiological monitoring, intraoperative flow cytometry), information presentation monitor, newly developed robotized operating table, surgeon cockpit and robotized video microscope.
Results: Prototype model of Hyper SCOT with intraoperative MRI, robotic operating table, robotic video microscope and surgeon cockpit has been installed in Tokyo Women’s Medical University. It particularly allows integration of data obtained with MEP and flow cytometry with intraoperative navigation and their demonstration on the monitor, which significantly improves efficacy and safety of surgery by supporting surgical decisions. Integration of this system with focused ultrasound will be tested in animal studies.
Conclusion: We have developed an integrated operation room “Hyper SCOT” consisting of networked surgical devices and newly robotic equipment. With its realization the operating room will no longer be simply a room, but an analogue of think tank, integrating various data, which will allow low-risk, high-precision, and maximally effective treatment.

Acknowledgements: This project is supported by the grant from Japan Agency of Medical Research and Development (AMED). We thanks all members of SCOT project.

Identifying Factors Triggering an Additional Resection and Determining Residual Tumor Volume on Intraoperative MRI

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Objective
In this analysis, we sought to identify variables triggering an additional resection (AR) and determining residual intraoperative tumor volume in intraoperative 1.5 tesla (i)MRI-guided glioma resections.

Methods
A consecutive case series of 224 mixed supratentorial glioma resections (WHO grade I-IV) from a prospective iMRI registry (inclusion 01/2011 - 04/2013) was examined with univariate and multiple regression models including volumetric data, tumor- and surgeon-related factors. The surgeon's expectation towards an AR inquired prior to iMRI was evaluated using contingency analysis. A machine-learning prediction model was applied to consider if anticipation of intraoperative findings permits preoperative identification of ideal iMRI cases.

Results
ARs lead to extension of surgery after iMRI in 70% of cases but did not translate into an accumulated risk for neurologic morbidity after surgery. Initial tumor volume determined frequency of ARs and was independently correlated with larger tumor remnants delineated on iMRI ($p<0.0001$). Larger iMRI volume was further associated with eloquent location ($p=0.010$) and recurrent tumors ($p<0.0001$) and with WHO grade ($p=0.0113$). Greater surgical experience had no significant influence on the course of surgery. The surgeon's capability to rule out an AR prior to iMRI turned out to incorporate guesswork (negative predictive value 43,6%). In a prediction model, AR could only be anticipated with 65% accuracy after integration of confounding variables.

Conclusion
Routine use of iMRI in glioma surgery is a safe and reliable method for resection guidance and is characterized by frequent additional resections after scanning. Tumor related factors were identified to influence the course of surgery and intraoperative decision-making while iMRI had a mutual value for surgeons of all experience levels. Commonly, the subjective intraoperative impression of the extent of resection had to be revised after iMRI review, which underscores the manifold potential of iMRI guidance. In combination with the failure to identify ideal iMRI cases preoperatively, our study supports a generous, tumor- rather then surgeon-oriented indication in glioma surgery.

Keywords: intraoperative MRI, glioma, additional resection, residual tumor, volumetric analysis

Comparisons between intraoperative MRI FLAIR and T2 tumor volumes compared to postoperative corresponding volumes in glioma surgery

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Abstract:

Introduction
Intraoperative MRI is a useful tool in the operative management of human gliomas. In non-contrast enhancing gliomas, and to a lesser extent enhancing tumors, the T2 and FLAIR signals are important targets to determine target volumes for resection margins. We hypothesized that intraoperatively (IO) obtained MRI T2 and FLAIR signal volumes might not reflect corresponding post-operative volumes due to tumor edema after resection and brain manipulation.

Methods
We examined 100 patients, average age 49.5 (range 16-82) 37 females and 63 males, who underwent intraoperative imaging during glioma surgery. We excluded patients with postoperatively diagnosed non-glioma pathology or if a new vascular injury was identified on diffusion-weighted imaging. Volumetric assessment of T2 and FLAIR signals were performed using the OSRIX image analysis program and ratios calculated for intraoperative and post-operative ratios of FLAIR and T2 MRI sequences for each patient.

Results
We examined 6 grade I gliomas (DNET, ganglioglioma, JPA) with postop/intraop FLAIR ratios of 3.30 +/-3.16 and T2 ratios of 3.15+/-3.74. In a similar fashion we found that similar ratios of FLAIR and T2 images for 25 Low-grade astrocytomas were 10.85+/-18.34 and T2 of 9.24+/-15.49; 10 oligodendrogliomas of 1.95+/-1.19 for FLAIR and 2.04+/- 1.51 for T2; 8 Anaplastic Astrocytomas with 4.30+/-7.91 for FLAIR and 3.33+/-4.69 for T2; 5 Anaplastic oligodendrogliomas with 2.34+/-3.11 and 2.04 +/-2.43 and 46 Glioblastomas with 2.11+/-2.89 and 2.22 +/-3.28.

Conclusions
Postoperative FLAIR and T2 signal volumes are significantly significantly higher than intraoperatively obtained corresponding volumes for all gliomas studied. Further work will be required but this study questions the validity of T2 and FLAIR images obtained intraoperatively.

Keywords: Flair, T2, signal changes, comparisons

Volumetric analysis using low-field intraoperative magnetic resonance imaging for 168 newly diagnosed supratentorial glioblastomas: effects of extent of resection and residual tumor volume on survival and recurrence

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Background
Extent of resection (EOR) remains controversial in therapy for glioblastoma (GBM). However, an increasing number of studies favor maximum EOR as being associated with longer patient survival. Residual tumor volume (RTV) has also recently emerged as a prognostic factor. Low-field intraoperative magnetic resonance imaging (iMRI) has contributed to improve the EOR of GBM. The purpose of this study was to analyze the relationships between EOR/RTV and overall survival (OS)/progression-free survival (PFS) in patients with newly diagnosed GBM using low-field iMRI.

Methods
Adult patients who underwent surgery for newly diagnosed supratentorial GBM between 2000 and 2012 were retrospectively reviewed. Three-dimensional volumetric tumor measurements were made. Multivariate analysis was used to evaluate the relationships between EOR/RTV and OS/PFS.

Results
Of 168 patients, 126 (75%) died and 154 (91%) showed tumor recurrence. Median OS and PFS for patients with iMRI were 19.3 months (95% confidence interval [CI], 15.4-23.7 months) and 9.5 months (95%CI, 7.8-10.8 months). Median preoperative tumor volume was 37.0 cm3 (interquartile range [IQR], 19.9-59.8 cm3). Median RTV was 0 cm3 (IQR, 0-1.6 cm3). Median EOR was 100% (IQR, 96.2-100%). In multivariate analysis, after controlling for age and Karnofsky Performance Status, EOR and RTV remained significantly associated with survival (hazard ratio (HR), 1.56; p=0.018) and recurrence (HR, 1.53; p=0.013). Maximum RTV for survival was 3 cm3.

Conclusions
This volumetric analysis for low-field iMRI showed that both EOR and RTV were significantly associated with survival and recurrence. We determined a threshold RTV of 3 cm3 as the maximum RTV associated with survival.

Keywords: extent of resection; glioblastoma; intraoperative magnetic resonance imaging; low field; residual tumor volume; threshold; volumetry

Intra-Class Correlations of Measured MRI Volumes of LITT-Treated High Grade Gliomas

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Abstract:

Introduction
Laser Interstitial Thermal Therapy (LITT) is a minimally invasive therapeutic option for the treatment of brain tumors. Previous studies have quantitatively followed the ablated volumes of high-grade gliomas, reported treatment volumes range from 28-100%, with no reported interobserver analysis. Because these volumes are subjectively measured, there is a need to establish the concordance between clinicians.

Methods
Utilizing Brainlab tumor analysis software (Brainlab, Germany), 5 physician users traced out tumor volumes slice-by-slice on 10 treated tumors in 8 patients. The participants were briefed with specific instructions and a demonstration on how to trace the enhancing borders of the tumor slice-by-slice. Volumes automatically calculated by the Brainlab software included pre-operative, intra-operative ablation and post-operative enhancing volumes. Data regarding size, cystic appearance, pathology, previous surgery, and demographics were included.

Results
The intra-class correlation coefficient (ICC) is based on variance components from an ANOVA and reflects the amount of variability between tumors. The ICC for preoperative, intraoperative, and postoperative volumes were 0.92 (95%CI 0.81-0.97), 0.90 (0.77-0.96) and 0.89 (0.74-0.96) respectively. The overall ICC was 0.72 (0.50-0.87). ICC comparisons were also made for each pair of readers (neuro-radiologist, neuro-oncologist, senior neurosurgery resident, neurosurgery junior resident) which resulted in pre-treatment ICC scores of 0.97, 0.91, 0.66, 0.94; Intra treatment scores of 0.97, 0.78, 0.90, 0.96; and post-treatment scores of 0.96, 0.81, 0.89 and 0.87. A Bland-Altman plot was also used to assess the differences in volumes.

Conclusion
The ICC gives a composite of the consistency of measurements made by multiple observers measuring the same quantity. The overall ICC of 0.72 means there is good correlation between observers in our study between measured volumes

Keywords: LITT, gliomas, intraoperative MRI, Intra-class correlations

Brain Tumour Resection: Determining Efficacy of iMRI

R Wirtz, M Scherer, R DeValle

"Results of Intraoperative Imaging – How do we determine necessity and efficacy"

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Beneficial impact of high-field intraoperative MRI on effectivity of pediatric low-grade glioma surgery

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Abstract:

Object
Intraoperative MRI (iMRI) is assumed to safely improve the extent of resection (EOR) in patients with gliomas. This study focusses on advantages of this technology in elective pediatric low-grade glioma (LGG) surgery compared to conventional surgery.

Methods
Surgical results of pediatric patients with conventional and 1.5 Tesla iMRI-guided elective LGG surgery were reviewed retrospectively. Tumor volumes, general clinical data, as well the EOR including reference radiology assessment, and PFS were analyzed.

Results
65 patients were included, 34 had conventional surgery before the iMRI-unit opened (pre-iMRI period), 31 were operated with iMRI-guidance (iMRI period). An intended complete resection (CR) was achieved according to the 3 months postoperative MRI (3/12 MRI) in 41% in the pre-iMRI and in 77% in the iMRI period ($p=0.05$). Of those patients with a postoperatively assumed CR, this proved to be true in only 50% in the pre-iMRI but in 81% in the iMRI period ($p=0.055$). Residual tumor volumes in the 3/12 MRI were significantly smaller in the iMRI cohort ($p<0.03$). By continuing the resection of residual tumor after the intraoperative scan (when the surgeon assumed a complete resection), the rate of complete resections was increased from 30% at the time of the scan to 85% in the 3/12 MRI.Mean follow-up of patients was 36.9 (3-79) months. PFS of patients after iMRI-guided surgery was noticeable better for the entire iMRI cohort, and in patients with postoperatively assumed CRs, but did not quite reach statistical significance. PFS was highly significantly better in patients with CRs compared to incomplete resections ($p<0.001$).

Conclusions
Significantly better surgical results (CRs) and PFS were achieved in patients with intended total resections by using iMRI. Therefore the use of high-field iMRI is strongly recommended for electively planned LGG resections in pediatric patients.

Keywords: pediatric, iMRI, low-grade

Contemporary Use of Intraoperative MRI in Germany – A Survey among the German Study Group of Intraoperative MRI (GeSGIM)

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Background
With a growing number of studies showing benefits of intraoperative MRI (iMRI)-guided surgery for extent of resection (EOR) and patient survival, numbers of iMRI centers increased all over the world. Recently, eight centers with iMRI in Germany formed a collaborative study group to investigate the impact of iMRI in neurosurgery on a multicenter basis, called the German Study Group of Intraoperative MRI (GeSGIM). This present study sought to outline the contemporary use of iMRI among the participating centers.

Methods
A questionnaire exploring general iMRI setup, sequences used during surgery, amount of intraoperative scans performed per case, additional surgical tools used in combination with iMRI and overall number of iMRI-cases and their indication for iMRI surgery within the past 5-years was sent to eight german iMRI centers. Research interests of centers were pooled to initiate multicenter collaborations.

Results
Completed questionnaires were retrieved from all eight centers. Seven of them were academic university institutions. Mean time of active iMRI use was 12±6 years. Two centers had >20 years of iMRI experience. Seven centers use 1.5 tesla (T) magnets, and one center a 0.15T magnet. All centers perform anatomic T1w and T2w/FLAIR imaging on a routine basis. Additional sequences used for selected cases included perfusion and diffusion-weighted imaging, diffusion tensor imaging, MR-spectroscopy, MR-angiography and resting-state functional MRI. On average among centers, more than one scan was performed per iMRI case (mean 1.6±0.5). Various tools including 5-ALA, intraoperative ultrasound, electrophysiology as well as awake surgery were combined with iMRI. Over the past 5-years, GeSGIM centers covered a total of 4973 iMRI cases. The majority of iMRIs were performed in gliomas (2482, 50%), followed by pituitary tumors (849, 17%) and other tumor resection controls (495, 10%). IMRI was also used for planning of stereotactic procedures or epilepsy surgery (968, 20%). The GeSGIM published one retrospective multicenter study in 2016. A prospective study evaluating iMRI for glioblastoma and a prospective registry for low grade glioma are recruiting since 2015.

Conclusion
The collaboration of eight German iMRI centers within the GeSGIM formed a powerful study group producing high annual iMRI case numbers for multicenter research. Anatomic imaging for resection control in glioma surgery was the principal indication for iMRI surgery which reflects the common goal among all GeSGIM centers to safely maximize EOR for the benefit of patients. However, every center presented with a unique iMRI setup and with variation in additional iMRI-sequences used depending on the research interest of respective centers. Future investigations will not only have to prove the benefit of iMRI in comparison to other resection guidance-tools, but also have to evaluate their combined use in order to tap the full potential of image guided surgery.

Keywords: intraoperative MRI, glioma, extent of resection, study group

Influence of intraoperative MRI on clinical outcome of patients with only subtotally resectable glioblastoma – a multi-center retrospective comparative analysis

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Objective
To evaluate influence of use of intraoperative MRI (iMRI) on extent of resection (EoR), neurological outcome and overall(OS) and progression free survival(PFS).

Methods
Patient data from 3 neurosurgical centers (years 2008-2013) was retrospectively reviewed including patients with primary glioblastomas (pGB) - or their recurrence (rGB). Tumors presenting unilocular growth, involving eloquent areas with intended STR were included. All patients underwent comparable adjuvant therapy. Imaging data was pseudonymized and assessed blinded by one central reviewer (neurosurgeon). Overall EoR (oEoR) was assessed based on pre-and postoperative tumor volume with iPlan 3.0 (Brainlab). In addition, a potentially resectable tumor volume (RV) was defined by the reviewer. Based on this data, a delta EOR (dEoR) achieved during the respective surgery was calculated. We calculated multivariate linear regression for oEoR and dEoR, binary regression for complications and Cox-regression for PFS and OS.

Results
Out of 101 patients, 88 presented pGBs and 13 presented rGBs. 46 patients underwent surgery without (w/o) iMRI, 38 patients with (w/) iMRI. In linear regression model controlling for age, tumor volume, neurophysiological mapping and use of iMRI no significant impact on any variable on oEoR was found. Yet using same model but assessing achieved dEoR we found a significant influence of iMRI only to minimize residual tumor ($p=0.03$). In binary regression model controlling for age, tumor volume, EoR, neurophysiological mapping and use of iMRI none of the variables showed a significant difference on complications. OS was significantly higher ($p = 0.01$) w/ iMRI (median OS = 10 months) vs. surgery w/o iMRI (mean OS = 9 months). Minimal EoR > 70% and maximum RV <5 cm3 independently showed a significant advantage ($p < 0.01$, $p = 0.01$) in relation to OS. Both criteria were found simultaneously in 48% of patients treated w/ iMRI and 24% of patients treated w/o iMRI ($p = 0.04$).

Conclusion
Our data show, that to achieve a survival benefit, maximum safe resection is an important goal also in lesion amenable only for STR. In our series, this goal was achieved significantly more frequently by the center using iMRI.

Keywords: iMRI, sub total resection, high grade glioma, glioblastoma

Prognostic factors concerning progression-free and overall survival in primary glioblastoma – follow up results of a randomized trial

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Background
In a randomized trial the use of an intraoperative MRI led to improved rates of complete tumor removal. In this study, complete tumor removal was associated with longer progression-free survival (PFS). However, overall survival (OS) was not addressed in the primary analysis. Moreover, follow-up was completed for PFS.

Methods
We performed a secondary analysis of survival data of patients with previously untreated, primary glioblastomas who participated in a clinical trial comparing conventional with intraoperative MRI-guided microsurgery that was published before. All patients underwent tumor removal between Oct 2007 and Jul 2010. Adjuvant therapy was administered according to interdisciplinary board decision and patient preference. We hypothesized that a radiologically complete resection of enhancing tissue (CRET) was associated with prolonged PFS and OS.

Results
We analyzed survival data of 35 patients with a median age of 63 years (range: 30-76). Median OS was 18.7 months. No patient was lost to follow up, all patients suffered from progression of their disease and all patients have died.

Regarding PFS, CRET was associated with longer PFS than patients with residual contrast enhancing tumor (6.8 vs. 3.4 months). A MGMT promotor methylation was associated with better median PFS in comparison to MGMT promotor non-methylated patients (7.5 vs. 4.6 months). Age was not significantly associated with PFS in univariate analysis ($p=0.7$). In Cox regression analysis, both MGMT promotor methylation status ($p=0.002$) and CRET ($p=0.012$) were significantly associated with PFS.

CRET had longer median OS than patients with residual contrast enhancing tumor (21.4 vs. 13.4 months, $p<0.05$). There was a trend for methylation of the MGMT promoter region to be associated with better median OS compared to absence of MGMT promoter methylation or an inconclusive test result (21.4 vs. 13.4 and 15.2 months, respectively, $p=0.05$). Age was not a statistically significant prognosticator ($p>0.1$). Following Cox regression analysis, MGMT promotor methylation status remained statistically significant ($p<0.05$), while CRET did not ($p=0.14$).

Conclusion
This is a secondary analysis of data derived from a randomized trial. As in the primary analysis, both MGMT promotor methylation and were independently associated with better progression-free survival. Although it was not powered to assess overall survival, our data corroborate the importance of the molecular marker MGMT for patients' prognosis. CRET was a significant factor according to univariate analysis, but did not reach significance in a multivariate model, most likely because of small sample size.

Keywords: Glioblastoma, Prospective randomized trial, Prognostic factors, Progression-free survival, overall survival

Awake craniotomies for glioma resection in an intraoperative MRI suite: analysis of 168 cases

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Object
The object of this study was to report our large experience of awake craniotomies in the intraoperative high-field (1.5T) MRI suite.

Introduction
Intraoperative MRI is a tool that can enhance extent of resection in glioma surgery coupled with awake craniotomy and electrophysiological monitoring (EM).

Methods
From a prospective database, the authors obtained and evaluated the records of 168 patients who underwent awake craniotomies for glioma resection with EM at MD Anderson Cancer Center between January 2010 and December 2015.

Results
48 (30%) tumors were low-grade and 111 (70%) were high-grade. The average duration of surgery was 7:13 hours, and the average time awake during surgery was 2:14 hours. 34% of patients benefitted from additional resection after intraoperative scanning. The final average extent of resection was 86.8%, and gross total resection (GTR) was achieved in 88 patients (55.3%). Of these, 63 (71.6%) had high-grade tumors and 25 (28.4%) had low-grade tumors. On average, greater EOR was achieved in high grade (92.4%) than in low-grade (81.0%) tumors ($p<0.002$), but the rate of GTR was not different between low- and high-grade tumors Greater EOR was also achieved in patients with negative cortical stimulation (91%) than those with positive cortical stimulation (84%) ($p<0.041$). At 30 days post-op, 31 patients (19.5%) reported complications, most commonly speech impairment (n=17, 10.7%) and focal motor deficits (n=13, 8.2%). The incidence of post-op deficits was no different between patients with positive and with negative stimulation.

Conclusions
The use of intraoperative MRI with awake craniotomy allowed for a greater extent of resection in 54 patients (34%), the majority of which (72.2%) had high-grade tumors. Awake craniotomy techniques with electrophysiological monitoring can be seamlessly integrated using intraoperative MRI.

Keywords: Intraoperative MRI, glioma

The impact of intraoperative MRI examination in glioma surgery

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Background
Intraoperative MR examination in glioma surgery can increase the extent of resection and also in higher ratio of cases achieve the gross total resection (GTR).

Methods
From the first moment the intraoperative MR examination was available in our institution all patients undergoing the glioma surgery with intraoperative MRI were prospectively followed in the study. Before the surgery the surgeon has declared whether the gross total or partial resection will be achieved. During the glioma surgery intraoperative MR examination (3T) was performed based on surgeon´s request. The gross total resection was achieved if no residual tumor was detected on T2 (LGG) or postcontrast T1 (HGG) images. All images were analyzed by independent neuroradiologist.

Results
From April 2008 to August 2016 602 glioma surgeries with intraoperative MR examination were performed in 531 patients (57 patients underwent 2 surgeries, 7 underwent 3 procedures). Biopsies were excluded from the evaluation.

High-grade gliomas (HGG) represent two thirds of all procedures (405 HGG compared to 197 LGG). In HGG group of intended partial resections (203 cases) in 67 cases resection continued after first MRI (33%). In 33 cases GTR was achieved (16%). In HGG group of 202 cases, where GTR was planned, resection continued because of residual tumor in 90 patients after MR examination (44%) and GTR was achieved in 63 of them. In last 112 HGG cases the procedure was stopped after MRI examination. In this group GTR was achieved in 105 patients (93%). Probable tumor remnant was revealed in 12 patients (confirmed on postop. MRI in 7 cases), but it was decided not to continue the surgery. In the whole HGG group of gliomas gross total resection was accomplished in 201 patients (50% of glioma resections).

LGG group represent 197 resections. Partial resection was presumed in 97 cases. Also in this group GTR was possible in 10 cases, but resection continued after iMRI in 41 patients (42%). In GTR group (100 resections) residual tumor after iMRI was found in 42 cases and procedure continued in 37 surgeries. In the whole LGG group in 96 cases GTR was achieved (49%).

In general one iMRI was sufficient in most cases, but in 2 procedures 3 intraoperative examinations were performed and in other 69 cases two iMRI scanes were made.

Conclusions
Intraoperative MR examination increase possibility to achieve radical resection in glioma patients. In approximately 50% of glioma resections complete resection is possible.

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Keywords: glioma, gross total resection, intraoperative MRI

Safety, value, and feasibility of continuous intraoperative electrophysiological monitoring in 1.5T iMRI-guided surgery

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Introduction
The combined use of intraoperative high-field MRI (iMRI) and electrophysiological monitoring (IOM) is often not applied on a routine basis due to concerns on possible side-effects. This is mainly based on sorrow to leave the skin-electrodes in-situ for intraoperative scanning, as burnings might occur and the magnetic field might disturb the fine electrical currents needed for proper neuromonitoring. However, if used together, both technologies might bring significant advantages for the treatment of patients. Therefore we have evaluated the safety and results of the combined use of both technologies.

Methods
The setup, surgical, imaging and clinical results of 110 patients with eloquent intracranial lesions with the combined use of 1.5T iMRI and IOM were analyzed.

Results
187 iMRI scans were performed with straight Platinum/Iridium IOM needles in place, resulting in a total experience of using more than 4000 electrodes in the iMRI. No complication (ferromagnetic or relevant heating/burning of skin) was caused by the combined use of both technologies. MR imaging quality was not influenced by leaving the electrodes in situ. Surgically induced severe postoperative sensorimotor deficits were seen in in 11.8%. The surgeon's intraoperative estimation of a "complete resection" proved to be true postoperatively in 90.3%. If the resection was stopped due to worsening of IOM, postoperative MRI revealed residual disease to be located in direct vicinity of eloquence in 27 of 28 cases, but not in other parts of the resection cavity. Of these patients, only 7% (2 of 28) had relevant new persisting neurological deficits after 3 months. In 82 (74.5%) of all patients the resection was continued after the iMRI scan, whereat in only 18 (16.4%) the resection was already completed at this point. In addition to proving safety and efficiency of both technologies, we have photo-documented special pitfalls in positioning of electrodes and cables to ensure a safe treatment.

Discussion
The combined use of IOM and 1.5T iMRI is feasible and safe, if complications are avoided by careful preparation of each patient. The complementary use of both technologies might result in more radical resections at comparable surgically-induced neurological deficits. If available and indicated, the combined use of IOM and iMRI should be performed on a routine basis.

Keywords: IOM, iMRI, Monitoring

The patients' view: impact of extent of resection and intraoperative imaging on health-related quality of life in high-grade glioma patients – results of a multicenter observational study

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Objective
To assess influence of extent of resection (EoR), use of intraoperative imaging on health-related quality of life (HRQoL) in high-grade glioma (HGG) patients in a prospective multicenter study.

Methods
We analyzed 162 patients suffering from a HGG during their first year after resection using EORTC QLQ-C30&BN20 questionnaires. We assessed influence of EoR, use of 5-aminolevulinic acid (5-ALA), intraoperative MRI (iMRI) and the combination of both on sum scores for function and symptoms as well as several neurological single items. In mixed model analyses, adjustments for age, Karnofsky-Performance-Status (KPS) and eloquent location were performed.

Results
In the mixed model, EoR in general did not significantly influence HRQoL ($p=0.10$). Yet, patients receiving subtotal resection (STR) vs. patients with biopsy showed significantly better QoL, role and cognitive function ($p=0.04$, $p=0.02$ and $p<0.01$, respectively). Combination of iMRI&5-ALA reached the highest EoR (95%) followed by iMRI alone (94%), 5-ALA alone (74%) and no imaging (73%). Thereby, neurological symptoms were lowest and functioning score highest after combined use of iMRI&5-ALA, without reaching significance ($p=0.59$).

Conclusion
STR compared to biopsy led to significantly better HRQoL and less neurological symptoms in HGG patients in our prospective series. An escalated use of intraoperative imaging increases EoR with stable or slightly better HRQoL and less neurological symptoms.

Keywords: Quality of life; iMRI, 5-ALA, EoR, extent of resection

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Fluorescence guided Surgery

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How to evaluate optical imaging methods

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Fluorescence diagnostics in surgery of intracranial meningiomas: is it necessary?

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Introduction: Intraoperative fluorescence navigation has been widely used in malignant glioma surgery, however, its application in resection of other intracranial tumors is less studied.
Objective: This study was aimed at investigating the effectiveness of aminolevulinic acid (5-ALA) fluorescence navigation in meningioma surgery and at specifying the factors contributing to fluorescent effect.

Material and methods: Eighty eight patients (25 male and 63 female, average age 54 ± 13, ranging from 25 to 77 years) with intracranial menigioma eligible for 5-ALA guided surgery were enrolled in this study. To evaluate the extent of menigioma resection, Simpson grading system was used. Surgery was performed with the aid of operative microscope equipped with fluorescent module. Fluorescence intensity was graded as mild, moderate and bright. Twelve patients underwent la-

ser spectroscopic analysis for a quantitative fluorescence evaluation. Transcranial motor evoked potentials were recorded in cases of functionally significant zones proximity.

The results of our research were compared to the findings of similarly designed studies (2007-2016). Fisher's exact test was used to explore differences in subgroups. Kendall rank correlation coefficient was calculated to test the relation between quantitative parameters.

Results. Meningiomas were primarily diagnosed in 79 (89.8%) cases, 9 (10.2%) patients had repeated surgery for recurrent desease. Convexity meningiomas were found in 71 (80.68%) cases, skull base meningiomas - in 14 (15.91%), intraventricular in 2 (2.27%). One patient developed both convexity and skull base lesions. Multiple meningiomas were revealed in 11 of 88 patients. Grade I tumors were detected in 61 patients (mixed tumors – in 28, fibrous - in 12, meningothelial – in 10, psammomatose - in 8, angiomatous - in 3). Grade II type was determined in 25 patients and Grade III tumors - in 2 patients. Fluorescence was detected in 82(93.18%) patients showing the following intensity: bright - in 51 (62.2%) cases, moderate - in 21 (25.6%) and mild - in 10 (12.2%) cases. There was no statistically significant difference in fluorescence intensity between patients with primarily diagnosed meningioma (n = 79) and recurrent disease (n = 9). No relation between fluorescence intensity and tumor location (skull base [n = 71] or convex [n = 14]) was found (p = 0.97). No statistically significant difference in fluorescence rate between Grade I (n = 61) and Grade II-III (n = 27) tumors was observed (p = 0.07). However, in our series (n = 82) bright fluorescence prevailed for Grade II-III tumors (82.6%) compared to Grade I (54.2%, p = 0.0397).

No differences in fluorescence rate (p = 0,05) and intensity (mild to bright, p = 0,38) were revealed for Grade I meningioma subtypes. Visual fluorescence effect, as well as its intensity, was not significantly related to bone invasion by tumor (in 23 cases). There was no statistically significant correlation marked between Dexamethasone (n = 34, regardless of dose) or anticonvulsant (n = 17) prescription and fluorescence rate and intensity (p > 0.05). No relation between gastrointestinal diseases (p = 0.24) or glucose metabolism failure (p = 0.8) and fluorescence brightness was observed. The extent of tumor resection by Simpson was not statistically related to fluorescence rate or its brightness (p = 0.779).

The results of this research merged with the findings of 7 similarly designed studies published in 2007-2016 confirmed no statistically significant differences in fluorescence rate between Grade I and Grade II-III meningioma (fluorescent effect was detected in 296 [88.3%] of total 339 patients, p > 0.05). In our series Grade I subgroup showed higher fluorescence rate without statistical significance (OR = 5.02 95%CI 0.66-59.10, p = 0.07). Laser spectroscopy was used in 12 cases,

fluorescent index ranged 9.39 - 121.93 r. u. (average 32.64 r. u.) for meningiomas and 1-2 r.u. for intact brain.

Conclusion: 5-ALA-induced fluorescence navigation in patients with intracranial meningiomas was associated with 93.18% sensitivity (88.3% for merged data from 8 studies). No statistically significant difference in fluorescence rate between Grade I and Grade II-III tumors was observed, however, Grade II-III tumors showed higher fluorescence intensity. There was no influence of primary/recurrent meningioma, tumor location, tumor grading, steroids and anticonvulsants intake, gastrointestinal disease or glucose metabolism failure on fluorescent effect. Although we did not observe a statistical relation between the degree of meningioma resection and fluorescence intensity, in our opinion, 5-ALA-guided navigation is useful in detecting tumor remnants in some cases, especially in cases of dura and bone invasion. A further research is needed to evaluate the role of laser spectroscopy in this type of surgery.

Keywords: 5-ALA, meningioma,

i-CT, i-US and 5-ALA fluorescence in brain tumors surgery: over-treatment or useful tools combination?

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Introduction

Neuronavigation is routinely used in surgical resection of brain tumors. However, the brain-shift phenomenon may limit its use, particularly in cases of large or deep-sited lesions. Brain shift is responsible for a progressive loss of accuracy of neuronavigation during brain tumor surgery. We report our experience with the use of intraoperative Computed Tomography (i-CT) and 5-ALA fluorescence in brain tumor surgery. We also introduce a multimodal intraoperative imaging protocol to correct brain shift and update neuronavigation based on the combination of intraoperative Ultrasound (i-US) and i-CT.

Methods

57 patients (29 males, mean age 68.2), including 5 children, underwent microsurgical resection of brain tumors using i-CT. Histological diagnoses included high-grade gliomas (32) low-grade gliomas (12), metastases/other tumors (13). 47 patients underwent 5-ALA fluorescence-guided microsurgery. The last 18 patients (11 male, mean age 61.3) were prospectively recruited and included in a multimodal intraoperative imaging protocol combining i-CT, i-US and 5-ALA. The study protocol was approved by local ethic committee and all patients signed informed consent to take part in the study.

Navigated B-mode ultrasounds were used before and after dural opening to identify the lesion and correct, when necessary, brain shift. After completing the resection of fluorescent tumor, post-contrast iCT was performed in order to detect small tumor remnants and to allow further correction of brain shift. A final i-US check was performed to verify completeness of resection. Extent of tumor resection (EOTR) was evaluated by volumetric post-operative Magnetic Resonance performed within 48 hours after surgery. Brain shift was measured by comparison of pre-operative MR with i-CT images. The distances in millimetres (mms) by which pre-operative MR images had to be shifted to correlate with intraoperative CT images were measured along two main vectors: one parallel and one perpendicular to the gravity.

Results

The global rate of adjunctive resection after i-CT was 33.3% (19/57). In the prospective cohort combining i-Us and i-CT, adjunctive resection was performed in 9/18 (50%) cases (5 glioblastomas, 1 low-grade glioma, 3 metastases). In these cases fluorescence had not shown any pathological areas. Moreover, in other 6 cases (2 glioblastoma, 2 low-grade gliomas and 2 metastases) i-US identified hyperechoic areas initially interpreted as residual tumors, but not confirmed by i-CT. EOTR was 100% in all but 9 cases (only one in prospective series). In this case we were unable to detect residual tumor with i-CT and i-US.

The progressive shifting of the brain was documented and recorded during all procedures. Mean brain shift along the parallel vector was 15 mms, whereas perpendicular brain shift vector measured 4 mms, comparing i-CT with pre-operative imaging.

Conclusions

The combination of different intraoperative imaging modalities may increase safety and extent of resection. In particular, i-US seems to be highly sensitive to detect residual tumors, but it may generate false positive due to artefacts. Conversely, i-CT is more specific to localize remnants and allows a more reliable updating of neuronavigation. Our preliminary experience is promising, but further studies are needed to validate the best intraoperative multimodal imaging protocol.

Keywords: i-CT, i-US, 5-ALA, glioma, metastasis

Multimodality guidance for Glioblastoma resection

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Introduction
Present data have led to a general agreement that increased resection in GBM translates in longer Overall Survival for patients. Most of the data stem from work done over resection measured by T1Gd MRI, with the goal of surgery being complete resection of enhancing tumor (CRET). Many recent papers have focused on increasing the rate of CRET with intraoperative imaging, and on the relative merit of different intraoperative guidance tools to achieve the objective, especially with the use of 5-ALA or intraoperative MRI.

Methods
We review data available in the literature about multimodality guidance in GBM resection, and our own data on the combined use of 5-ALA, and intraoperative 3-T MRI, and of 5-ALA and Methionine-PET.

Results
Comparison of one imaging modality against another may be tricky, results depending a lot on the design of the trial, and the question asked.Few data are available about resection measured by anything different than T1Gd MRI, but resection guided by AA-PET, 5-ALA, FLAIR-MRI and ultrasound have all been reported as leading to increased survival in single center series. Our data for 5-ALA and AA-PET show both these techniques offer a target for resection slightly bigger than T1Gd, with good pathological correlation.

Discussion
GBM is a diffuse tumor, with an invasive border merging into the surrounding brain, TiGd is only a surrogate marker for tumor, and different imaging tools can show a different tumor volume. There is no pathology gold standard to measure and grade the histopathology from invasive areas of GBM, so all studies on this border are difficult to compare.

The comparison of one imaging intraoperative modality against other seems not to be the most important point as the different tools that can be used together if needed. More relevant is the the adequate use of each of them and global benefit for patients of the right combination. With any intraoperative imaging used, residual enhancing tumor should be not detectable, or very small and present only in areas at high risk of neurological deficit.

For the next years, surgical focus should be on getting more GBM patients to have proper surgery in centres with the right equipment and training and on collecting more data about resection beyond CRET.

Keywords: Glioblastoma, surgery, 5-ALA, Intraoperative MRI, Aminoacid-PET

Primary high grade glioma surgery using a combination of intraoperative magnetic resonance imaging and intraoperative fluorescence (5 – aminolevulinic acid): A single centre experience

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Background & Objective
The extent of resection (EOR) of tumor is a proven prognostic factor in patients undergoing surgery for suspected high grade glioma. A few recent publications have shown the importance of intraoperative magnetic resonance imaging (iMRI) with 5-aminolevulinic acid (5-ALA) fluorescence-guidance in order to maximally increase EOR. The objective of our study was to calculate the effect on survival of patients with high grade gliomas using both iMRI and 5-ALA fluorescence-guidance as intraoperative adjuncts.

Methodology
Thirty-seven patients, from March 2013 till March 2015,with Gadolinum-enhancing high gliomas on preoperative MRI undergoing surgical excision were included in a prospective study. Surgeries began under white-light conditions. Intermittently, a blue light filter was switched on to search for remaining tumor tissue not visible to naked eye. When gross total resection (GTR) was thought to be achieved, iMRI was done to check for any contrast-enhancing part left behind. Surgery was concluded or resumed based on the iMRI findings. Histopathological examination of the tumor tissue was done. All patients underwent immediate postoperative MRI at the end of the surgery to calculate the EOR.

Results
Our results for follow up till January 2016 showed that out of the total 37 patients, 17 patients died during the follow up period and 11 patients are still alive. The mean survival was 587.1 days and median survival was 491 days with a range of 342 to 943 days. When we compare it with the average survival in patients with high grade gliomas, i.e. 9 to 14 months, it shows that both the abovementioned modalities are very helpful in increasing the EOR and in turn the overall survival.

Conclusion
Use of iMRI as well as fluorescence-guidance are appropriate methods to improve the extent of resection in surgery of contrast-enhancing gliomas. Best results can be achieved by complementary use of both modalities. The follow up for the patients till December 2016 is still under process.

Keywords: glioma, intraoperative magnetic resonance imaging (iMRI), ALA dye, extent of resection

Comparison of imaging data of intraoperative MRI, 5-Aminolevulinic acid and linear array intraoperative ultrasound and histopathology: Results of a prospective study on patients harboring a glioblastoma

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Objective
For appropriate use of available intraoperative imaging-techniques in glioblastoma(GB) surgery it is crucial to know the potential of the respective techniques in tumor detection. Thus, aim of the study was to assess histopathological basis of imaging results of intraoperative MRI(iMRI), 5-aminolevulinic-acid(5-ALA) and linear-array-intraoperative ultrasound(lioUS)

Methods
We prospectively compared the imaging findings of iMRI,5-ALA and lioUS at 99 intraoperative biopsy-sites in 33 GB-patients during resection control. Histological classification of specimens, tumor load, presence of necrosis, presence of vascular malformations and MGMT promotor state were correlated with imaging findings.

Results
Solid tumor was found in 57%, infiltration zone in 42% and no tumor in 1% of specimen. However, imaging was negative in iMRI in 49%, using 5-ALA in 17% and in lioUS in 21%. In positive imaging results, share of solid-tumor was highest in 5-ALA(65%) followed by lioUS(60%) and lowest in iMRI(55%). In comparison to 5-ALA, iMRI had a high share of solid tumor in specimens when showing intermediate results. Sensitivity for invasive tumor was higher in 5-ALA (84%) and lioUS(80%) than in iMRI(50%). We found a significant correlation of 5-ALA with classification of specimen, presence of necrosis and microproliferations. Methylated MGMT promotor correlated with positive findings in 5-ALA. lioUS and iMRI showed no correlations with histopathological findings.

Conclusion
All of the assessed established imaging techniques detect infiltrating tumor only to a certain extent. Only 5-ALA showed a significant correlation with histopathological findings. Interestingly, tumor remnants in an MGMT methylated tumor are more likely to be visible using 5-ALA as in unmethylated tumors.

Keywords: histopahtology, iMRI, 5-ALA, intraoperative ultrasound

Fluorescein-guided surgery with a dedicated filter on the surgical microscope for resection of high-grade gliomas: Results of the multicentric phase II fluoglio study

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Introduction
Fluorescein is a dye that accumulates in cerebral areas with a damaged blood-brain barrier (BBB). Given the High-grade glioma (HGG) effect on BBB, fluorescein can be used during its resection to better visualize tumor tissue and improve extent of resection (EOR).

Methods
In September 2011, a prospective phase II clinical trial was started to evaluate safety and efficacy of fluorescein-guided resection of HGG. 46 patients were finally enrolled in the two clinical centers (Besta Institute, Regensburg University Hospital) for the evaluation of primary endpoint (31 males and 15 females, mean age 63, range 40-74). Fluorescein was intravenous injected after general anesthesia induction or immediately at the entrance in the OR for awake surgery (5-10 mg/Kg). Tumor was removed with microsurgical technique and fluorescence visualization by BLU400 (used in the first six patients enrolled) or YELLOW560 filters on the Pentero microscope (Carl Zeiss Meditec, Germany). Primary endpoint of the study was extent of resection, calculated on an early postoperative MRI. In 13 patients, biopsies were performed at the tumor margin to evaluate sensitivity and specificity of fluorescein in tumor tissue identification. Patients were submitted to post-operative Stupp Protocol and followed-up every 2 months.

Results
The median pre-operative tumor volume was 28.75 cm3. No adverse reactions related to fluorescein administration were registered. Contrast-enhanced tumor was completely removed in 82.6% of the patients. Sensitivity and specificity of fluorescein in identifying tumor tissue, based on intra-op biopsies, were 81% and 79% respectively. With a mean follow-up of 14 months, PFS-6 rate and median survival based on Kaplan-Meier curve were respectively 60.4% and 13 months.

Conclusion
Fluorescein-guided technique seems to be a safe method to obtain a high-rate of complete resection of HGG at the early post-operative MRI.

Keywords: fluorescein, HGG, tumor resection, intraoperative fluorescence, Y560

Fluorescein-guided surgery with a dedicated filter on the surgical microscope for resection of pilocytic astrocytomas: A multicentric retrospective preliminary study

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Introduction
Pilocytic astrocytomas (PAs) are intracranial tumors predominantly found in children. Their optimal management is gross-total resection (GTR), associated with longer survival. Sodium fluorescein (SF) is a water-soluble organic dye that accumulates in cerebral areas with altered Blood Brain Barrier, like it happens with tumors enhancing at pre-operative MRI. The utilization of SF is associated with a better visualization and improvement of resection for several tumors of the central nervous system. The aim of this study is to retrospectively evaluate the effect of SF on visualization and resection of PAs.

Methods
Surgical database IRB-approved from three Neurosurgical Departments (Besta Institute, Regensburg University Hospital, Liv Hospital, Istanbul), were retrospectively reviewed to find PAs removed with fluorescein-guided technique from October 2013 to December 2015. There were 30 patients (13 males, 17 females, mean age 29, 14 patients in pediatric age), with a mean pre-operative tumor volume of 56 cm3 (available in 17 patients). Four of them were recurrences. SF was intravenously injected (3-5 mg/kg) after general anesthesia induction. Tumor was removed with microsurgical technique and fluorescence visualization by YELLOW560 filter (Pentero microscope, Zeiss Meditec, Germany). Surgical database were reviewed regarding the degree of intra-operative fluorescent staining, the results of immediate post-operative MRI, and post-operative outcome.

Results
Bright fluorescent staining was reported in 22/30 cases (73%). In 6/30 (20%) cases no comments were available. In 2/30 (6%) cases fluorescein was considered not helpful. GTR was achieved in 15/26 (58%) cases with intended surgical removal (in 11 cases a subtotal, i.e >90% of the tumor mass, was achieved). In 4 cases a biopsy only was performed. No adverse events were registered.

Conclusion
Fluorescein-guided technique with YELLOW560 filter is a safe method to guide visualization and resection of pilocytic astrocytomas in adults and children, obtaining a high-percentage of total removal at early post-operative MRI.

Keywords: fluorescein, pilocytic astrocytomas, intraoperative fluorescence, Y560, tumor removal

Fluorescein-guided surgery with a dedicated filter on the surgical microscope for resection of spinal intramedullary tumors: A multicentric retrospective preliminary study

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Introduction
Spinal intramedullary tumors are a subgroups of central nervous system (CNS) tumors primarily consisting in ependymomas and astrocytomas. Surgical resection may be challenging due to strict relationship with viable peritumoral areas. Furthermore, gross-total resection (GTR) is not always feasible also due to difficulties in discriminating between tumor tissue and normal spinal cord. Sodium Fluorescein (SF) is a water-soluble organic dye that accumulates in CNS areas with altered Blood Brain Barrier. The utilization of SF improves visualization and resection of several tumors of the CNS. No data are available on the use of SF during resection of spinal intramedullary tumors.

Methods
Surgical database IRB-approved from three Neurosurgical Departments (Besta Institute, Regensburg University Hospital, Liv Hospital, Istanbul), were retrospectively reviewed to find spinal intramedullary tumors surgically removed by fluorescein-guided technique from January 2014 to December 2015. There were 10 patients (5 males, 5 females, mean age 50.1), including: 5 ependymomas, 3 hemangioblastomas, 2 astrocytomas. Fluorescein was intravenously injected (5 mg/kg) after general anesthesia induction. Tumor was removed with microsurgical technique and neurophysiological monitoring (PESS, PEM, D-wave) and fluorescence visualization by YELLOW560 filter on the Pentero microscope (Carl Zeiss Meditec, Germany).

Results
No side effects related to fluorescein were found. Fluorescein was considered helpful in distinguishing tumor from viable tissue in 6 out of 10 cases (60%). In two cases no notes were available in the surgical database regarding this issue. In one case little fluorescence was reported. In one case the contribution of fluorescein was considered inconsistent. GTR was achieved in all cases. All but one patient improved or remained stable at mRS at last follow-up compared to preoperative period.

Conclusion
Our preliminary data suggested that fluorescein-guided technique with YELLOW560 filter is a safe method to guide visualization and resection of spinal intramedullary tumors.

Keywords: fluorescein, spinal ependymomas, hemangioblastomas, astrocytomas, Y560, intraoperative fluorescence

Simultaneous Fluorescein Sodium and 5-ALA in Fluorescence-guided Glioma Surgery: A Comparison

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Background
Fluorescein sodium has generated renewed interest for off-label use in fluorescence-guided resections of malignant gliomas due to potential advantages such as bright fluorescence and the possibility of intravenous application. We sought to simultaneously visualize 5-aminolevulinic acid (5-ALA) derived protoporphyrin IX (PPIX) and fluorescein fluorescence in order to detect synergies between both methods.

Method
A specialized microscope system (Leica, Heerbrugg, Switzerland) was used to visualize of both fluorescein and PPIX fluorescence in each patient. 5-ALA was administered 4 hours prior to surgery (20 mg/kg). Fluorescein (4 mg/kg, 10% solution) was applied at two different time points, either before dura opening (n=2; 1 Glioblastoma, 1 recurrent low-grade glioma) or after resection of the tumor bulk (n=2, both Glioblastoma).

Results
Neither time point of application resulted in significant fluorescein fluorescence preferentially marking tumor tissue in the low-grade or the high-grade glioma patients. Fluorescein fluorescence was observed in the dura, cortex and vessels, and was found in oozing blood which contaminated the surrounding structures. Fluorescein extravasation was also noted in areas of surgical tissue injury. Specific PPIX fluorescence was observed in all three Glioblastoma (GBM) patients, but not in the low-grade glioma patient. Surprisingly, fluorescein did not appear to accumulate in viable, marginal tumor tissue with clear PPIX fluorescence. No surgical decisions were made based on fluorescein fluorescence. Due to the lack of exploitable fluorescein fluorescence this pilot study was prematurely closed.

Conclusions
Our observations do not support a useful role for fluorescein sodium in fluorescence-guided resections of gliomas.

Keywords: 5-ALA, Yellow

Dual-labeling with ALA and Fluorescein for fluorescence-guided resection of high-grade gliomas – technical report

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Objective
Fluorescence-guidance with 5-ALA helps improve resections of malignant gliomas. However, one limitation is the low intensity of blue light for background illumination. Fluorescein has recently been re-introduced into neurosurgery and novel microscope systems are available for visualizing this fluorochrome, which highlights all perfused tissues but has limited selectivity for tumor detection. We here investigate a combination of both fluorochromes, ALA for distinguishing tumor and fluorescein for providing tissue fluorescence of adjacent brain tissue.

Methods
We evaluated six patients with cerebral lesions suggestive of high-grade glioma. Patients received ALA (20mg/kg) orally four hours before induction of anesthesia. Low dose fluorescein (3mg/kg i.v.) was injected immediately after anesthesia induction. Zeiss Pentero microscopes (equipped either with Yellow560 or Blue400 filters) were used to visualize fluorescence. To simultaneously visualize both fluorochromes, the Yellow560 module was combined with external blue light illumination (Storz D-Light).

Results
Fluorescein-induced fluorescence created a useful background for protoporphyrin IX (PPIX) fluorescence, which appeared orange to red, surrounded by greenly fluorescent normal brain and edematous tissue. Green brain tissue fluorescence was helpful in augmenting background. Too strong levels of blue illumination obscured PPIX fluorescence. Unspecific extravasation of fluorescein was noted at resection margins, which did not interfere with PPIX fluorescence detection.

Conclusion
Dual labeling with both PPIX and fluorescein fluorescence is feasible and gives superior background information during fluorescence guided-resections. We believe this technique carries potential as a next step in fluorescence-guided resections if completely integrated into the surgical microscope.

Keywords: PPIX, fluorescein, malignant glioma, ALA, fluorescence-guided resection

Intraoperative Computed Tomography State of the Art and Perspectives

Moderators: JC Tonn, A Unterberg, A Raco

State of the art: Intraoperatvive CT as registration machine

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Double room CT with a sliding gantry for intraoperative imaging: feasibility and workflow analysis of an interdisciplinary concept

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Objective The growing demand for short turnaround time and cost effectiveness in operating room management also affects intraoperative imaging and the management of its complex and expensive devices. Aim of this study was to examine our experience with a series of patients, treated with aid of a new double room CT scanner (DR-CT), which was used by several operative disciplines simultaneously.
Methods A multislice CT scanner was installed in between two operating rooms, connected to a neuronavigation system with direct transfer of imaging data. Several neurosurgical teams (skull base, spine, vascular neurosurgery, stereotactic surgery) used the DR-CT simultaneously. In addition it was used by the Department of Surgery. For image acquisition, the sliding gantry moved into one operating room, whereas a moving wall was closed to the other one. Image quality, workflow, utilization rate, intraoperative CT (iCT) related complications and surgical procedures were analyzed retrospectively. Non-parametric data were compared by using the Mann-Whitney-U-Test.
Results Intraoperative CT-imaging in the DR-CT was undertaken 347 times between 01/09/2014 and 31/07/2016. Neurosurgical procedures included 23 skull base surgeries, 38 spine fusions, 8 vascular surgeries and 265 stereotactic procedures since 01/02/16. The iCT was used 11 times by the Department of Traumatology and once by the Department of Thoracic Surgery. Workflow analysis showed similar patient turnover times with (n=69) and without iCT (n=333) (Operating-room-cutting time: 41 ± 13 minutes vs 33 ± 9 minutes, p=0.53; suture-cutting time: 95 ± 18 minutes **vs** 100 ± 44 minutes**,** p= 0.97; time from the end of surgical measures to release of the next patient 25 ±16 minutes vs 40 ±44 minutes, p= 0.43). The hygienic cleaning of the gantry took 27±11 seconds

(n=43). The iCT utilization rate increased from 2.6±1.4 per month during the introduction phase (09/14-06/15) to 24.8±25.3 per month during the routine use phase since 07/15, but did not differ significantly (p= 0.09). There were no iCT related complications and no operative procedure was hampered by ongoing iCT imaging in the neighboring OR.
Conclusions The concept of DR-CT in two operating rooms facilitates a broader and multidisciplinary use, increases the utilization rate and does not prolong patient turnover times. Substantial changes of the surgical workflow or surgical instruments are not necessary. The DR-CT may facilitate the availability of iCT for stereotactic procedures, intraoperative resection control, perfusion imaging and angiography, and implant control.

Keywords intraoperative CT, sliding gantry, double room CT scanner, computed tomography

Intraoperative use of AIRO CT: initial experience in glioma surgery

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Intraoperative imaging is largely used in glioma surgery for assessing extent of resection and the occurrence of surgical related complications. In this work we explore the uselfulness of an intraoperative CT (AIRO Brainlab) during surgical procedure for supratentorial and infratentorial glioma removal. AIRO CT has some theoretical advantages: the large gantry allows to perform intraoperative image acquisition without changing the surgical patient position; the rapid time of image acquisition. Aim of the work was to evaluate the feasibility of use, and the impact on surgical flow and decision. Surgery in all the cases was performed with the aid of extensive brain mapping techniques and intraoperative neurophysiological tools, which were used to define the margin of resection, despite of imaging.

AIRO set up was used in 298 cases; in 185 cases an asleep awake asleep anesthesia was performed. No problem of patient positioning, clamp placement, or patient discomfort (in the awake cases) was registered, after implementing clamp fixation device. On AIRO bed, patients were positioned either supine, lateral, or prone.

AIRO was used in 298 procedures to rule out surgical related complications immediately after skin closure, when patient was still lying on AIRO bed: CT scan was able to detect surgical related complications (hematoma) in 4 cases on operative bed, which in 2 cases was followed by surgical revision. The eventual abnormalities seen on AIRO CT were confirmed in a set of patients by submitting the patient to CT scan, without documenting any differences.

In 34 cases an intraoperative CT was performed (25 large frontotemporo insular tumor, 6 intraventricular tumor, 2 posterior fossa tumors, 1 case of intraventricular cyst). In all cases, the surgical position was not changed for imaging. Intraoperative images were fused with pre operative CT and MR images to help in the evaluation. In 23 cases, intraoperative US images were also available for comparison. Intraoperative imaging was feasible in all cases, with an average time for case preparation and image acquisition of 17 minutes (patients are connected in all cases to full intraoperative neurophysiological monitoring, which was kept in place during imaging time). In case of limbic tumors, where the resection was accomplished according to functional boundaries, AIRO intraoperative imaging confirmed the achievement of tumor border and rule out intraoperative complications. In case of 4 intraventricular tumors, intraoperative images showed the persistence of tumor remnants in 3 cases and were used to further extend and complete resection. In the case of intraventricular cyst, AIRO CT was used to assist and optimize the placement of intraventricular intracystic catheter during the procedure. In case of posterior fossa tumor, AIRO allowed performing intraoperative imaging acquisition with the patient in prone position, and evaluating the achievement of a complete tumor resection, or the intraoperative localization of deep located tumor remnants. More work has to be done to optimize image quality and to implement contrast enhacement acquisition.

Keywords: glioma surgery, intraoperative CT

Diagnostic iUltrasound

Chairs: A Nabavi, C Senft, A Steno

Use of 3D Ultrasound imaging and navigated Ultrasound aspirator in the operations of patients with low grade gliomas.

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Professor Norwegian University of Science and technology (AJ)

Tumor tissue in patients with low grade gliomas may be very difficult to delineate with the operation microscope. There are different tools available to improve the resection grade. The technique most widely used is probably awake operations with neurophysiological stimulation. Other tools to improve the resections are intraoperative MR and Ultrasound. Our preferred tool has been 3D Ultrasound

Since 1998 our patients have been operated asleep and guided by 3D US. In eloquent areas, we import 3D MR with fMRI and tractography into the navigation system and combine it with 3D US and sometimes stimulation. The resection is done with navigated ultrasound aspirator.

46 consecutive LGG patients undergoing primary surgery guided with 3D-US between 2008-15 were investigated for extent of resection. Pre- and postoperative FLAIR or T2-weighted images were segmented in 3D Slicer by a radiologist blinded to clinical outcome. The median resection grade was 93,4 %. A resection grade of more than 90% was achieved in 59% of the patients. Radiological complete resection was obtained in 33%.

The impact on survival cannot be evaluated in the above material due to short observation time. In 75 consecutive patients operated with the same method from 1998- 2009 the median survival is more than 14 years

The data will be discussed and compared to results obtained by other techniques.

Advances in intraoperative ultrasound applied to neurooncology

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Intraoperative real-time ultrasound to characterize intracerebral pathomorphology and guide surgery has been present since the 1980's. However, due to slow improvements in image quality and the emergence of superior technologies such as CT and MRI the value of ultrasound has until recent years been underestimated.
Ultrasound was used by neurosurgeons for the first time in 1950 by French et al who attempted to gain echo signals from cerebral pathologies in autopsy brains. The emergence of B-mode imaging with anatomical slices in the early 1980's brought a great improvement in usability. However, it would still take nearly four decades to reach a level of technology which provides enough image quality and ease of use for the modern neurosurgeon. Superior image quality due to greatly improved probe technology using high frequencies, beam focusing and advanced software processing together with image fusion provides the neurosurgeon with a very competitive tool for intraoperative imaging. Emerging silicon era ultrasound transducer technology based on semiconductor technology instead of traditional piezoelectric crystal (PZT) could possibly unleash another paradigm shift by overcoming the inherent limitations of PZT technology. This means a great increase in number of elements, tremendously increases bandwidth which relates to resolution, improves frequency range (low to ultrahigh frequency in one transducer) and much simplifies manufacturing. Image quality set aside ultrasound is still currently the only truly real-time modality for intraoperative imaging. Hopefully, it will finally step out of its own shadow.

3-D reconstructed, navigated and contrast enhanced Ultrasound in 100 brain tumor patients

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Objective
A convincing intraoperative resection control in surgery of malignant brain tumors is associated with a longer overall survival of the patients. B-mode ultrasound (BUS) is a well-known intraoperative imaging application in neurosurgical procedure but it´s limited in the differentiation of tumor, tumor borders and edema or tumor remnants. The aim of this clinical study is the investigation of contrast enhanced and 3D-reconstructed ultrasound (CEUS) in surgery of glioblastoma regarding the uptake of the contrast agent after tumor resection, imaging quality and comparison with the postoperative MRI.

Methods
We investigated prospectively 100 patients suffering from a intracerebral brain tumor lesions. All have undergone surgery with the support of neuronavigation in our Department of Neurosurgery. Ultrasound imaging for resection control was acquired before dura opening and at the end of tumor resection defined by the neurosurgeon. A high end ultrasound (US) device (Toshiba Aplio XG®) with linear probes for B- Mode and contrast mode was used. The navigation and 3D reconstruction was performed with the LOCALITE SonoNavigator® and the images were transferred digitally. The used contrast agent was SonoVue® by Bracco®. Subsequently the ultrasound images were segmented compared to the corresponding postoperative MR data.

Results
From 100 included patients 48 suffered from glioblastoma (GBM), 33 Patients with a metastasis,1 Astrocytoma grade I, 4 Astrocytoma grade II, 6 Astrocytoma grad III, 5 meningeomas, 2 oligodendrogliomas and 1 patient with an intracerebral abscess. No side-effects caused by the contrast agent occured. Fast arterial and venous phases after bolus injection were observed in the glioblastoma patients. The tumor was always well distinguishable from the normal brain tissue. Extensive dynamic uptake of contrast agent was observed in 44 patients (92%, GBM). In those 92% 3D-CEUS resulted in equivalent or better tumor imaging compared to B-mode US. In 48%, delineation and imaging were improved by CEUS. Twenty-one of the 48 patients showed no recurrences and a gross total resection (GTR) was planned before surgery. GTR was achieved in 14 of these 21 patients (67%) with median time to progression (TTP) of 9 months.

Conclusion
3D-contrast enhanced intraoperative ultrasound (CEUS) is a save and convincing intraoperative imaging modality. High resolution images in real time 3D could be acquired in 5 to 10 minutes. Gross total resection and incomplete resection of glioblastoma were sufficient demonstrated with CEUS intraoperatively. The application of US contrast agent could be a helpful imaging tool for resection control.in glioblastoma.

Keywords: Ultrasound, intraoperative resection control, 3D reconstruction

Navigated 3D-ultrasound versus conventional neuronavigation during awake resections of eloquent low-grade gliomas

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Background
The extent of tumor resection (EOR) is a significant predictor of survival in low-grade gliomas (LGGs). Although navigated intraoperative 3D-ultrasound (3DUS) is increasingly used during neurosurgical procedures, a study comparing its impact on the EOR during awake resections (ARs) of LGGs with conventional neuronavigation is lacking. The authors present a series of ARs of eloquently localized LGGs guided by 3DUS. Radiological and functional results were compared to the series of ARs of eloquently localized LGGs guided by conventional neuronavigation.

Methods
During a 4-year-period (September 2006 - August 2010) 21 ARs of LGGs guided by neuronavigation (neuronavigation series) were consecutively performed in Department of Neurosurgery in Bratislava. During another 4-year-period (August 2010 - July 2014) 28 ARs of LGGs guided by 3DUS (3DUS series) were consecutively conducted at the same institution. In both patients series the eloquent cortical and subcortical structures were intraoperatively detected by direct electrical stimulation. Four patients (2 from each series) were excluded due to a premature end of surgery; 45 patients constituted the whole research cohort.

Results
There was no significant tumor volume difference in both series. The mean EOR was significantly greater (p=0.016) in 3DUS series (90.5%), as compared to neuronavigation series (81.8%). The significant difference was confirmed in multivariate analysis involving age, sex and preoperative tumor volume (p=0,046). No severe or moderate permanent deficits occurred in both series; 1 permanent minor deficit in neuronavigation series and 2 minor deficits in 3DUS series were observed.

Conclusions
3DUS further improves the EOR during ARs of eloquently localized LGGs, as compared to conventional neuronavigation.

Keywords: glioma, awake resection, 3D-ultrasound, navigation

Navigated intra-operative ultrasound in cerebral gliomas surgery: impact on extent of resection and patient outcome – a single center experience

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Background
The achievement of the maximum extent of resection (EOR) is the main goal in the surgical treatment of cerebral gliomas. Intra-operative ultrasound (ioUS) is a real-time technique that permits to overcome the limitations of conventional neuronavigation (NN) caused by brain shift and brain deformation. In this study we evaluate the impact of real-time neuronavigation (NN) combining ioUS and pre-operative MRI to maximize extent of resection (EOR) in gliomas surgery and we correlate it also with neurological outcome and quality of life of the patients.

Methods
We retrospectively evaluated a series of 42 cases operated on for cerebral gliomas. All cases were evaluated considering age, location of the tumor (eloquent, non-eloquent), pre- and post-operative Karnofsky Performance Status (KPS), pre- and post-operative tumor volume, EOR and possible post-operative complications.

Results
In 27 cases (64.3%) an EOR≥98% was achieved, whereas in 23 (54.8%) of these 27 an EOR=100% was reported. In 13 cases (30.9%) the ioUS evaluation at the end of resection allowed us to identify residual tumor. The average level of resection was 93% for eloquent lesions and 98.2% for non-eloquent lesions. In 11 cases (26.2%) we observed additional neurological deficits, 8 of these showed a rapid improvement in the immediate post-operative period. At discharge there was an improvement of KPS average (>80).

Conclusions
With ioUS real-time NN we obtained good results both in terms of EOR and of neurological outcome. In our experience the technique has proved to be reliable in the resection of lesions in non-eloquent areas. In resections in eloquent areas we achieved again comparably good results in combination with cortical and sub-cortical mapping techniques.

Keywords: ioUS, echographic neuronavigation, extent of resection, glioma

Surgery for insular low-grade gliomas: visualization of lenticulostriate arteries using navigated 3D-ultrasound power-Doppler

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Background
Resection of insular low-grade gliomas (LGGs) is challenging; in case of intraoperative injury to the lenticulostriate arteries (LSAs) the usual result is a dense hemiplegia. LSAs are usually localized just behind the medial tumor border but they can also be encased by the tumor. Thus, exact localization of these perforators is important. However, intraoperative localization of LSAs using conventional neuronavigation can be difficult secondary to brain-shift. We present a novel method of intraoperative LSAs visualization by navigated 3D-ultrasound power-Doppler. This technique enables almost real-time imaging of LSAs and evaluation of their shift during insular tumor resections.

Methods
Nine patients harboring insular LGGs were consecutively operated in our center using visualization of LSAs by navigated 3D-ultrasound power-Doppler. In all cases, the 3D-ultrasound data were repeatedly updated in order to compensate the brain-shift and display the actual position of LSAs and tumor residua.

Results
Successful visualization of LSAs was achieved in all cases. During all surgeries, the distance between the bottom of the resection cavity and LSAs could be accurately evaluated.

Conclusions
Visualization of LSAs by navigated 3D-ultrasound power-Doppler is a useful tool that may help to prevent injury of LSAs during removal of insular LGGs. However, reliability of this method has to be carefully evaluated in further studies.

Keywords: Lenticulostriate arteries, glioma, insula, 3D-ultrasound, power-Doppler

Intra-operative ultrasound based correction of brain-shift

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Introduction

Accurate mapping between pre-operative MR images and the patient is key to reliable neuro-navigation, however difficult to achieve due to errors introduced by patient-to-image registration and brain-shift. Consequently, pre-operative MR images cannot always be trusted for accurate neuro-navigation. In order to correct for these effects, intra-operative ultrasound imaging is an attractive solution. However, interpretation of the ultrasound images may present an important obstacle in the efficient use of this modality, as most neurosurgeons are not specifically trained in ultrasound anatomy of the brain. Automatic MR-to-ultrasound registration has the potential to correct the MR data for inaccuracies due to initial mapping and brain-shift. The MR images can then be used actively during tumor resection.

In this work, we have combined the open-source intra-operative navigation platform CustusX [1] and automatic image registration software [2] to test the hypothesis that correction for brain-shift can be automatically performed in the operating room, and be accurate enough for brain tumor resection guidance. The results were evaluated both intra-operatively and post-operatively.

Methods

Ten glioma patients were prospectively included in the study. The study was approved by the Regional committee for medical and health research ethics and all patients provided written informed consent. The pre-operative MR images (T1 and FLAIR) were registered to the patient using five fiducial markers. The intraoperative setup consisted of a navigation rack with our open-source platform CustusX [1]. The navigation system was connected to an optical position tracker (NDI Polaris Spectra; Northern Digital, Canada) and a GE Vingmed E9 ultrasound scanner with a GE 11L linear array transducer (GE Vingmed Ultrasound, Norway). The image registration software (ImFusion Suite, ImFusion GmbH, Germany) automatically aligns MR and ultrasound based on a robust image-based algorithm which is invariant to the different appearance between the modalities. It was run as an independent package called from the navigation system interface, and the result was automatically loaded.

Immediately after image registration, the surgeon evaluated the rigid registration result by inspection of the correspondence between the MR and ultrasound volumes. Post-operatively, the results were evaluated by placing ten landmarks in the image volumes and computing the distance between points before and after registration.

Results

In six out of ten cases, the correction was judged sufficiently accurate to continue the resection based on the corrected images. In three cases, the rigid registration was unable to accurately correct the images due to non-rigid deformation of brain-tissue. In one case, the navigation setup failed causing the mismatch between the images to be larger than the capture range of the algorithm. In the six successful cases, the mean distance between corresponding landmarks was reduced from 6.46 mm to 2.68 mm.

Discussion

We have shown that automatic correction of brain-shift is feasible in the operating room. The registration improved navigation accuracy in six of ten cases. The method should be further extended to non-rigid registration for increased accuracy, and also applied to other datasets such as fMRI and DTI.

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Keywords: brain-shift, ultrasound, image registration

“The Art and Future of Diagnostic Ultrasound”

Moderators: C. Nimsky, D Netuka, M Hadani

Intraoperative Ultrasound – Scope and Application in Contemporary Neurosurgical Practice

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Intraoperative US has been one of the earliest adjuncts introduced into the neurosurgical operating room. 2DUS (real-time, gray scale imaging) was the commonest mode of use. Initial efforts and attention were focused on understanding normal and pathological features using this form of imaging. As confidence and experience accumulated efforts shifted towards objectively assessing tumor delineation and comparative examinations with other imaging modalities (CT and MR). Suboptimal image resolution and lack of orientation, continued to hamper the effective use of IOUS as a reliable intraoperative guide, especially as rapid strides in CT and MR imaging provided a much more useful alternative. With focused efforts on improving transducer features, superior image resolution is now possible. Further, combination with navigation technology has provided a very powerful real-time imaging tool especially during tumor and vascular neurosurgery. Features like navigated US (especially 3D) and coregistered multimodal (US-MR) image navigation have greatly eased image orientation and allowed rapid traversing of the learning curve in the use of IOUS. The maximum impact of IOUS has probably been felt in the realm of tumor surgery. Use of IOUS has shown to improve tumor delineation (particularly gliomas’ both low- and high-grade), allow more complete and radical resections and thereby improve outcomes. Besides, use of complementary US modalities like Power Doppler and Color flow imaging have shown to be very useful in vascular surgery. Further, the scope of application of IOUS is limited only by its ability to insonate the object of interest (tumor, vessles, cyst, ventricles, etc). Considering the ease of use, widespread accessibility and low-cost nature, IOUS can be a potentially useful adjunct during a range of neurosurgical procedures. This talk follows the evolution of IOUS as a intraoperative adjunct and its current state of use in contemporary neurosurgical practice.

Keywords: intraoperative ultrasound, navigated ultrasound, contemporary scope, review

Contrast enhanced ultrasound and elastosonography in neurosurgery: concept and trends.

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Fondazione IRCCS Istituto Neurologico C. Besta

Intra-operative ultrasound (ioUS) represents one of the most employed intra-operative imaging in neurosurgery. The first description in neurosurgery is dated 1978 by Reid with B-mode ioUS application. Since then technological advances in US imaging brought numerous improvements in routine practice; with different extremely informative imaging modalities comprising B-mode, Doppler imaging (Power-, spectral-, color-doppler), fusion imaging with pre-operative imaging, along with other advanced modalities such as contrast-enhanced ultrasound (CEUS) and elastography.
CEUS envisages the use of contrast agent (UCA) that allows nowadays for a continuos dynamic imaging. Ultrasound contrast agents (UCA) are gas filled microbubble injected intravenously that, when insonated with low power ultrasound, start to resonate emitting an harmonic echo, analyzed through a specific software, representing exclusively the echo signal from the CA. UCA, because of its physical properties, behaves as purely intravascular CA and consequently the intensity of the enhancement is related to the vessels density in the district under exam. This feature allows CEUS to be applied in different neurosurgical settings: in neuro-oncology, for cranial and spinal tumor localization, characterization, surgical planning and resection control; in skull base and vascular surgery to localize major vessels, asses perfusion patterns, flow assessment, protection of vital structures, surgical control.
Elastosonography allows to perform an ultrasonic palpation of the area in exam, detecting changes in stiffness of various tissues after a given stimulus. The elastographic imaging depends on tissue properties that differ from those involved in B-mode imaging, thus having the potential to provide unique information about the pathologic tissue. Initially described for other organs (liver in e.g.), in the last few years has been applied in neurosurgery. Under the technical aspects, elastography can be acquired through different techniques, in particular the most relevant for neurosurgery are shear wave, and strain elastography. Nevertheless the main aspect is the possibility to obtain an instrumental palpation of the tissue, thus providing the surgeon with information about the stiffness of the lesion, and allowing for both better identification of lesion margins, and lesion characterization.
Both CEUS and elastosonography are applied in almost all the organs of the body for diagnostic and therapeutic purposes and their usage is regulated by guidelines written among scientific societies. Our presentation will focus on the actual applications of CEUS and elastography in neurosurgery and on their future evolution as diagnostic and therapeutic tools.

Intraoperative ultrasound technology: systems, transducer, algorithms.

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Ultrasound is one of the most common used imaging technologies based on its ease of use, cost-effective devices available and the non-ionizing nature of the imaging physics. Furthermore, the real-time capabilities together with the possibilities provided by non-invasive imaging can already be used for intraoperative applications but the users have to be familiar with ultrasound imaging characteristics including the artifacts and limitations present.
In the planning of neurosurgery the transcranial application of ultrasound imaging often lacks image quality and has to be improved compared to the current state of technology available.
In order to improve the benefits of ultrasound imaging for the neurosurgery lots of technologies developed especially for transcranial ultrasound imaging and other diagnostic ultrasound applications have to be transferred to clinical practice. Commercial systems often transfer only these technologies to their clinical ultrasound scanners that can be brought to market for the best value of the manufacturer after a long time of product development.
The limitations for existing system often are caused by specific hardware and software requirements that are not met by existing platforms commercially available. To surpass this limitation we usually use very flexible ultrasound research systems (electronics, transducers and software) with certification for clinical use to adapt to new ideas and approaches.
Current developments by the ultrasound research community are presented that can lead to improvements in transcranial and intraoperative ultrasound applications in the future. This includes high channel count electronics to be used with matrix array transducers for real-time volumetric imaging including advanced beam reconstruction and signal processing as well as ultrafast ultrasound imaging techniques that enable new kinds of doppler blood flow dimensions, vector velocity imaging, super resolution imaging and functional imaging of the brain based on ultrasound measurements.
Beside these technical advances in the measurement technologies new ultrasound devices enable new fields of application for ultrasound imaging. This includes MR-compatible ultrasound devices to be used next to the patient inside an MRI scanner to benefit from different advantages of both imaging modalities as well as the combination of laser generated ultrasound with advanced optoacoustic detection systems.

Visions and new Applications

Chairs: A Golby, J Weinberg, C Roder

Neurosurgical Robotics: A Review

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Continuum Robotics: Principles and Potential for stereotactic surgery

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Intra-operative quantification of Tool-tissue Interaction Forces: A Digital Footprint of Surgical Performance

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Background
In addition to intra-operative visualization, the sense of touch forms an integral part of surgical performance and learning. From our observation in image-guided robotic surgery using neuroArm, we observed tool-tissue interaction forces in neurosurgery were relatively low (<1N) and with minimum variability. We have gone on to develop a unique force sensing bipolar forceps called SmartForceps to examine tool-tissue forces of conventional surgery, and to determine if force analysis can be used as an objective assessment of surgical skill.

Methods
Through installation of four strain gauge sensors on to bipolar forceps connected to a signal conditioning and visual display system, SmartForceps was developed. Force data was obtained from 26 neurosurgical patients, across 16 neurosurgeons (three groups: novice, intermediate, experienced) for pre-determined surgical tasks. Normative baseline force ranges were obtained using force profiles (mean and maximum forces, and force variability) from experienced surgeons, then standardized force profiles and force errors (high force error [HFE], Low force error [LFE], and force variability error [FVE]) were analyzed and compared among groups.

Results
The rates of each error were correlated with unsuccessful task trial evaluated by video analysis. Total mean and maximum forces of novice surgeons were generally higher than those of intermediate and experienced. Force variability of intermediate and novice surgeons was higher than that of experienced. The rate of HFE and FVE inversely correlated to level of experience. The rate of LFE was increased in intermediate and novice surgeons when compared to experienced. There was no difference in LFE between intermediate and novice surgeons. Stepwise discriminant analysis showed that combined use of these error rates discriminated the surgeon groups with 87.5% accuracy.

Keywords: Robotics, Force-Feedback

Short Communication

Chairs: M Chicoine, S Kantelhardt

Does Envelopment in Corticospinal Tract and Cortical Surfacing predict neurological outcomes after Surgical Resection of Lesion involving Motor Pathway? A New Evaluation Scale

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Object
Preservation of functions is essential in surgical resection of lesions involving the motor pathways. The aim of this work is to evaluate the effect of anatomical features of lesions located in the motor pathway on neurological and functional outcome.

Methods
45 patients suffering from gliomas and metastases involving the motor pathways have been studied for what concerns motor functions (MRC) and quality of life (KPS) after surgical treatment. Patient-related, surgery-related and lesion-related data were recorded to identify relations with motor outcomes. Cortical surfacing of the lesion and degree of envelopment of the lesion within corticospinal tract have been investigated with preoperative MRI sequences and tractographic reconstructions.

Results
Means of MRC pre and 7days post-operative were respectively 3,6 ± 2,24 and 3,8± 2,26 for upper limbs, 4,1 ± 2,31 and 4,4± 2,30 for lower limbs. Patients stable or improved at 7 days from surgery were 82,3%. The anatomical features investigated have been summed up in a single score (ES - Envelopment/Surfacing). In case of ES classes V and VI a total cumulative predicted worsening rate was 24,2% and 14,8% respectively. There was a risk of worsening of 1,682 times greater for the higher ES classes (IV-V-VI).

Conclusions
The topographic features of lesion are crucial in the prediction of outcome. The new proposed score (ES score) can be useful to stratify motor function prognosis.

Keywords: Tractography,

Multimodal Image-based Virtual Reality Pre-surgical Simulation and Evaluation for Trigeminal Neuralgia and Hemi-facial Spasm

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Background
High-resolution three-dimensional (3D) magnetic resonance imaging (MRI) has demonstrated its ability to predict fine trigeminal neurovascular anatomy. However, the feasibility of the visualization of neuro-vascular confliction with multimodal image-based virtual reality endoscopy has not been proved.

Objective
To address the feasibility and predictive value of MRI based multimodal virtual reality endoscopy in detecting and assessing features of neurovascular confliction (NVC), particularly regarding the degree of compression exerted on the root, in patients who underwent microvascular decompression (MVD) for classic primary trigeminal neuralgia (TN) and hemi-facial spasm (HFS).

Methods
This prospective study includes 42 consecutive patients who underwent MVD for classic primary trigeminal neuralgia or hemi-facial spasm (HFS). All patients underwent a preoperative 1.5T MRI with T2-weighted 3D sampling perfection with application-optimized contrasts by using different flip angle evolutions (3D-SPACE), 3D time-of-flight (TOF) magnetic resonance angiography (MRA), and 3D T1-weighted gadolinium-enhanced sequences in combination, while 2 patient underwent a preoperative 7.0T MRI with the same imaging protocol. Multimodal MRI images were then transferred to 3D Slicer and co-registered with each other. The images were then reconstructed three-dimensionally to generate virtual endoscopy images of cerebella-pontine angle. Evaluations were performed by 2 independent observers and compared with the operative findings.

Results
For prediction of NVC, image analysis corresponded with surgical findings in 40 cases. Of the 2 patients in whom image analysis did not show NVC, 1 did not have NVC at the time of intraoperative observation, while the other one was found to have vein compression. MRI sensitivity was 97.6% (40/41), and specificity was 100% (1/1). The kappa coefficients (k) for predicting the offending vessel, its location, and the site of compression were 0.882, 0.813, and 0.942, respectively. Image analysis correctly defined the severity of the compression in 39 of the 42 cases. The k coefficients predicting the degree of compression were 0.813, 0.833, and 0.852, respectively, for Grades 1 (simple contact), 2 (distortion), and 3 (marked indentation).

Conclusion
MRI based multimodal virtual endoscopy using 3D SPACE in combination with 3D TOF-MRA sequences proved to be reliable in detecting NVC and in predicting the degree of root compression, the outcome being correlated with the latter.

Keywords: Microvascular decompression, MRI, neurovascular confliction, virtual reality, trigeminal neuralgia

Individual testing during awake craniotomy. A personal medicine application in glioma surgery?

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We all know that awake craniotomy in an useful tool trying to reach maximal safe resection. We also know that prep imaging valuation, mainly functional MRI has a low sensitivity rate to identify motor and sensory speech cortical areas when compared with AC mapping. Generally we use naming, counting, dual task, PPTT and free speech tests during cortical and subcortical mapping, but we know that language is a very complex net and varies between people. We started to individual testing our patients, based on main hobbies and work activities, adding to the regular tests some personal tasks like a musician play guitar, a priest pray, engineerier make specific counting etc... We compared these 62 patients with our historic regular tested 158 patients. We noticed that we could reach GTR in 60 % compared with 72 % in regular testing group but had only 11% neurologic complication compared with 23%. Our procedure became less aggressive but safer. In our point of view the personal testing should be consider as a good manner to map eloquent areas.

Keywords: awake craniotomy, maximal safe resection, glioma surgery, limitations of fMRI and DTI

Signature vessel registred augmented reality in neurosurgery

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Introduction
Augmented reality is defined as a virtual overlay upon real-world images that can be integrated during microsurgery in the operative microscope.

Objective
To investigate the practicality, precision and usefulness of signature vessel registered augmented reality during a variety of neurosurgical procedures, and to evaluate its advantages over traditional neuronavigation, as well as over previously reported augmented reality systems.

Methods
Segmentations of structures identified as Reference Objects (RO), Signature Vessles (SV) and Target Objects (TO) from preoperative image datasets (CT, MRI, 3D DSA) were performed using BrainLab's Iplan platform (BrainLab, Feldkirchen, Germany). Patients and the neuronavigable operating microscope (Zeiss Pentero 600/900; Zeiss, Oberkochen, Germany) were referenced to the neuronavigation station (Kolibri™; BrainLAB, Feldkirchen, Germany), allowing for image injection. No additional hardware was required.

Results
3D model injection was performed for intraoperative guidance in the clipping of n=9 aneurysms, for the resection of n=4 AVMs, during n=3 extracranial-to-intracranial bypass procedures, n=1 skull base procedures and n=2 glioma. Qualitative and quantitative observations will be presented and compared to previous experience of 104 interventions in the hybrid suite, 97 with AR and 19 with SV registered AR.

Conclusions
The described setup dramatically improved precision of 3D information incorrelation with the surgical field, increasing the surgeon's comfort during all procedures. It is a safe, easy and intuitive means of intraoperative image-guidance, which may ultimately reduce complications and improve outcome.

Keywords: aneurism, augmented reality, neuronavigation, signatur vessels

iMRI-Guided Spine Surgery: Pilot Study for Anterior Cervical Discectomy and Fusion (ACDF)

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Introduction

Building off earlier experience with the use of mid-field Magnetic Resonance Imaging (MRI) to guide spine surgery (Woodard 2001), Brigham and Women's Hospital has launched a program to perform Anterior Cervical Discectomy and Fusion (ACDF) using a 3 Tesla MRI system (IMRIS/Siemens Verio, Minnetonka MN USA). ACDF is performed to alleviate radiculopathy due to a herniated or degenerative cervical disc on about 150,000 patients per year in the USA. The reported complication rate ranges from 9-20%, with a low rate of serious complications including hematoma, dural penetration, and esophageal perforation (Lied 2008, Hacker 2000, Fountas 2007). The risk of dural penetration may be further reduced if the procedure is modified. Intra-operative MR imaging will serve to monitor the degree of spinal cord decompression, detect injury and hemorrhage, and enable correlation with post-operative symptoms and follow up imaging.

Methods

Patients are consented in accordance with the hospital's Institutional Review Board and undergo the ACDF procedure while lying supine on the MRI table. The spine MRI array coil embedded in the table is used for posterior coverage and a sterility wrapped body array coil is placed above the surgical field prior to imaging for anterior coverage.

The surgery, under general anesthesia, involves seven steps: (1) horizontal displacement of the neck muscles, trachea, and esophagus to access the disc, (2) vertical distraction of neighboring vertebrae to reduce pressure on the disc to be removed, (3) removal of the nucleus and annulus of the disc, (4) removal of osteophyte complex lining the spinal foramen, (5) removal of the posterior longitudinal ligament (PLL), (6) insertion of a bone graft in-place of the disc, and (7) immobilization of the neighboring vertebrae with a metallic plate to enable eventual fusion of the vertebrae with the graft. MR imaging is performed prior to incision and following steps 3, 4, and 5 (time points I, II, III, and IV).

All surgical instruments and hand pieces are non-ferrous. A custom titanium Clear-Line retractor system (NSI Health Systems, Centennial, CO USA) and carbon fiber Caspar distractor (Life Instruments, Braintree, MA US) were produced. The distractor frame and titanium pins, which stay in place during imaging, were tested for heating induced during imaging and image artifact. Although surgical drills are marketed for use near MRI scanners, the necessary bits are not available. A Sonopet ultrasonic aspirator with a Saber tip (Stryker, Kalamazoo, MI USA) is instead used to remove disc and posterior osteophytes. The consoles for the Sonopet, monopolar, and bipolar, and headlight remain outside the 5 gauss line. The ferrous foot pedal for the Sonopet was weighted down to prevent magnet attraction by the MRI scanner. Figure 1 depicts the surgical setup.

An MR visible fiducial is placed on the skin at time point I to plan the incision location. A sterilized doughnut shaped fiducial (PinPoint, Beekly Medical, Bristol CT, USA) is sutured to the muscle to identify the level to be resected. The retractor and blades were removed prior to each imaging time

point to eliminate metal artifact. Patient displacement between the surgical location and the imaging location (MRI scanner isocenter) is about 1 meter. The imaging protocol consists of axial and sagittal T2-w FSE (TR/TE 2500/84ms, ETL 18, FOV 19x19 cm, Matrix 320x256, 2 averages, BW 60 Hz/pixel, ST 2.0 mm, Acquisition Time 3:36 min). Prior to continuing surgery, the anterior array coil is removed and a layer of sterile drapes is added.

In a later phase of the study, step 5 will be eliminated and outcomes compared.

Results

At this time, surgery has been performed on one patient at level C4-C5 with no complications; the patient reports no radiculopathy. Transition time between imaging and surgery was less than five minutes and image acquisition duration was 15 minutes per time point (~2:20). The surgical portion of the procedure was about 2:40, consistent with similar procedures in the conventional operating room.

Sequential Axial T2-w images are acquired at various time points I-IV. Despite the presence of the metal distractor pins, the canal is visualized without artifact. Serosanguineous fluid fills the resected disc space. Cord decompression and increased CSF flow is observed at time point III (after osteophyte removal), with a smaller degree of decompression at time point IV (after PLL removal).

Discussion and Conclusion

ACDF procedures with frequent intra-procedural MRI imaging are possible, providing immediate feedback on results of surgical intervention.

Follow up imaging is planned for six weeks from the date of surgery. It is unknown if further decompression will occur once edema from surgical trauma resolves and if there will be differences in the patient population with and without PLL removal.

An ideal MRI receive coil could be developed to further improve signal-to-noise ratio (SNR). Surgical access requires the neck be hyperextended and the distractor frame and pins protrude from the neck, requiring the body flex array coil be offset several inches from the neck, thus reducing SNR. A coil that conforms to the neck, which includes a hole for surgical access, may enable more ideal coil placement.

Others have shown that iMRI-guidance to plan and execute lesion removal in near the cervical spine with a transoral approach is viable (Dhaliwal 2012). Imaging was successfully used to show decompression of the spinal cord and ensure completeness of resection.

A controversy exists in the surgical community regarding the necessity of the removal of the PLL (step 5, time point IV). An analysis of the incremental decompression due to the removal of the PLL (step 5), subsequent omission of the step, and correlation with clinical outcome may lead to a change in clinical practice. If this step, with its attending risk of dural penetration, is omitted, reduced complication rates are expected. Furthermore, with iMRI-guidance, visualization of hematoma prior to closure is also expected to reduce the complications.

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Keywords: spine, ACDF, disk, fusion, MRI, magnetic resonance imaging, intra-operative

3D intraoperative Ultrasound and MR image-guidance: pursuing an ultrasound-based management of brain shift to improve neurosurgical navigation

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Purpose
Brainshift is a major open issue in neuronavigation. Incorporating intraoperative ultrasound (iUS), with advanced registration algorithms, within the surgical workï¬ow is regarded as a promising approach for better understanding the brainshift. This study was conceived: i) to provide 3-dimensional (3D) deformation fields corresponding to brainshift; ii) to improve navi-gation accuracy; iii) to quantify novel image registration algorithm.

Materials & Methods
Eight patients harboring brain tumors were studied. A 3D free-hand iUS machine, paired to navigation (iNav) system, was employed at 3 timepoints during surgery to detect brainshift through registration of iUS images. Target registration error (TRE) was measured. Rigid and Elastic registration algorithms were evaluated.

Results
The mean TRE based on 3D-iUS was significantly lower than iNav before (2.7 vs 5.9 mm; p=0.001) and after dural opening (4.2 vs 6.2 mm, p=0.049), but not after resection (6.7 vs 7.5 mm; p=0.426). The iUS depicted a significant (p=0.001) dynamic spatial course of brainshift throughout the 3 timepoints. The accuracy was improved through rigid and elastic registra-tions by 29.2% and 33.3%, respectively, after dura opening, and by 5.2 % and 0.4%, after re-section. The surgical time (p=0.047) and the pre-operative lesion volume (p=0.021) correlated with the TRE at the end of the resection.

Conclusions
3D-iUS systems can improve the detection of brainshift and significantly increase the accuracy of the navigation in a real scenario. 3D-iUS can thus be regarded as a robust, reliable, and feasible technology to enhance neuronavigation.

Keywords: glioma, intraoperative US, brainshift

Stimulated Raman scattering microscopy provides histologic images for automated machine learning-based histopathologic diagnosis of fresh human brain tumor specimens

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Introduction

Accurate intraoperative histopathologic diagnosis is essential for optimal surgical management of brain tumors. Standard methods are labor-intensive and prone to processing artifacts that complicate interpretation and may delay surgical care. Stimulated Raman scattering (SRS) microscopy is a label-free optical process that provides rapid, high-resolution, digital histologic images of fresh, unprocessed human brain tumor specimens. Stimulated Raman histology (SRH) provides the opportunity to employ automated machine learning techniques to improve the accuracy of intraoperative histopathologic diagnosis and avoid inter-rater variability between neuropathologists.

Methods

We aimed to develop a machine learning technique that would provide rapid and accurate histopathologic diagnosis of human brain tumors using intraoperative SRH images. Multilayer perceptron (MLP), a supervised artificial neural network model, was utilized and incorporated 12,879 400x400μm SRH fields of view (FOVs) from our series of 101 patient tissue samples that included non-lesional histoarchitecture or the histoarchitecture of 3 lesional categories of brain tumors (low-grade glial, high-grade glial and non-glial tumors). The four diagnostic classes were selected because they provide critical information for informing surgical decision-making during brain tumor surgery. The MLP was designed as a fully-connected, 1,024-unit, 1 hidden layer, neural network that comprises 8 sequential layers using backpropogation. We used WND-CHRM, an open-source image classification program that calculates 2,919 image attributes, for MLP input to assign quantified attributes to each FOV.

Results

Training of the MLP was performed using a 71 patient training set that was exclusive from a 30 patient test set. Leave-one-out cross validation was used to gauge performance of MLP-diagnosis versus neuropathologist's diagnosis. MLP accurately differentiated lesional from non-lesional specimens with 100% accuracy in our series when evaluated at the sample level. Additionally, the diagnostic capacity of the MLP for classifying individual FOVs as lesional or non-lesional was excellent, with 94.1% specificity and 94.5% sensitivity (AUC=0.984). Among lesional specimens, the MLP differentiated the lineage as glial or non-glial with 90% accuracy at the patient level. The most common, or modal, FOV diagnostic class predicted by the MLP was 90% accurate in predicting the sample diagnostic class rendered by pathologists. Misclassified cases included images with FOVs composed of normal or gliotic brain intermixed with areas of tumor infiltration.

Conclusion

We developed a MLP technique that provides rapid and accurate automated histopathologic diagnosis of fresh brain tumor specimens using SRH. The accuracy and overall ability of our machine learning in automated detection of lesional status and diagnostic category provides a proof-of-principle for how the MLP could be used for rapid automated diagnostic predictions.

Keywords: stimulated Raman scattering microscopy, machine learning, computer-aided diagnosis, neural network, Stimulated Raman histology, Raman spectroscopy, intraoperative microscopy, glioma, brain tumors

Contrast-enhanced Ultrasound and quantitative ICG videoangiography with FLOW800: a synergistic approach for real time verification of maintained local brain perfusion and aneurysm occlusion in a case of complex distal MCA aneurysm

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Introduction

Distal clipping and EC-IC bypass represent a valid alternative for surgical management of complex MCA aneurysm. Direct intraoperative visualization of both aneurysm flow exclusion and normal parenchimal perfusion after distal clipping and bypass would be ideal in this kind of surgical procedure.

In this paper we present an innovative approach in which Contrast-enhanced US (CeUS) and quantitative ICG videoangiography with FLOW800 have been used in a synergistic way to confirm flow exclusion and normal local brain perfusion after distal clipping and STA-MCA bypass in a case of distal partially thrombosed MCA aneurysm.

Case Report

A 19-year-old male with a history of partial seizures was diagnosed by MRI and DSA to harbor an unruptured fusiform partially thrombosed 14 mm aneurysm of a distal branch of the left MCA, with perianeurysmatic edema. After a clinical and radiological work-up excluded a micotic aneurysm, the patient was scheduled for a surgical approach combining EC-IC bypass and parent artery occlusion. First of all, a bypass was realized connecting the parietal branch of STA and the distal branch of left MCA. Then, the aneurysm was proximally explored: it appeared very adherent to functional brain parenchyma. It was not possible to visualize the parent vessel and therefore to clip it, because of the large aneurysm volume e brain edema. For this reason, the strategy switched to clipping of the efferent artery, immediately distal to the aneurysm. The whole intervention was guided by imaging (neuronavigation Stealth ST), ICG videoangiography and CeUS. CeUS was performed at the beginning of the procedure to study aneurysm characteristics, and after the bypass and distal clipping to verify in real time the effect of distal clipping on the aneurysm, i.e. flow exclusion from arterial circulation with slow contrast movement inside the aneurysm. Quantitative ICG videoangiography with FLOW800 confirmed the normal local brain perfusion in the area distal to the aneurysmatic MCA branch, after the bypass.

The patient was submitted to post-operative CT-angio and DSA that confirmed aneurysm disappearance and patency of the bypass. Long-term MRI showed resolution of brain edema. At one year follow-up the patient is neurologically intact and has returned to normal life.

Conclusion

CeUS and quantitive ICG videoangiography could be used synergistically to study superficial brain perfusion and aneurysm characteristics in difficult vascular cases where complex procedures, including bypass and partial trapping, need to be proposed.

Keywords: complex MCA aneurysms, CeUS, FLOW800, ICG videoangiography, bypass, distal clipping

Horizon Lecture

Brain-Machine-Interface for Intelligent Prosthesis

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“Beyond Grayscale”

Chairs: G. Sutherland, L. Bello, V. Gerganov

Stimulated Raman Scattering Microscopy

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Depiction of the tumor-brain interface using label-free multimodal CARS imaging

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Tissue biomarkers: the next step for intraoperative imaging

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Stimulated Raman scattering microscopy provides histopathologic images for accurate intraoperative diagnosis of pediatric brain tumors

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Introduction
Accurate intraoperative histopathologic diagnosis is essential for optimal surgical management of pediatric brain tumors. Standard intraoperative histopathology suffers from intensive tissue preparation and processing artifact. Stimulated Raman histology (SRH) uses the intrinsic biochemical properties of fresh surgical specimens to provide label-free histologic images. We aimed to evaluate the ability of SRH to reveal histopathologic features of pediatric brain tumors for accurate intraoperative diagnosis.

Methods
Pediatric and young adult brain tumor patients (≤ 26 years) were prospectively enrolled over 18 months. Fresh surgical specimens were imaged intraoperatively using a clinical fiber-laser-based SRH microscope. Blinded reviewers evaluated SRH images for histopathologic features and diagnostic accuracy was calculated.

Results
Twenty-one patients were enrolled and histopathologic diagnoses included pilocytic astrocytoma(8), gangliogliomas(5), medulloblastoma(4), ependymoma(1), high-grade glioma(1) and germinoma(1). SRH provided rapid histologic images with sub-micron resolution for all specimens without tissue processing artifact. A virtual hematoxylin and eosin color scheme was developed to recreate standard light microscopy conditions. Diagnostic histopathologic features (e.g. pilocytic processes, small round blue cell morphology, etc.) were evaluated in 1,617 400μm x 400μm fields of view for the above listed tumor types. Using histopathologic features, SRH correctly diagnosed 32/33 (97%) fresh surgical specimens. Additionally, SRH provided unique intraoperative histologic data on immune cell infiltration not detected on standard light microscopy that improved diagnostic accuracy of tumor grade. Microglia infiltration predicted higher tumor grade with 98% specificity and 100% sensitivity.

Conclusion
SRS microscopy provides rapid, high-resolution, intraoperative images for accurate diagnosis of common pediatric brain tumors. Further investigation in a larger pediatric cohort is currently underway.

Keywords: Stimulated Raman scattering microscopy, Raman spectroscopy, intraoperative microscopy, pediatric brain tumors

High-resolution fluorescence microscopy for the identification of glioma tissue on a cellular level

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Optical Coherence Tomography in Neurosurgical Procedures

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Abstract:

Optical coherence tomography (OCT) is a well-established tool in dermatologic and ophthalmologic daily clinical practice and integrated regularly in ophthalmologic surgery. First clinical implementations in the field of neurosurgery focused on the definition of resection boarders in Glioblastoma multiforme, and reached technical limitations. Our research instead focuses on the study of micro anatomy, micro pathology, angioarchitexture and hemodynamics in vivo to gain more insides into the pathogenesis and treatment of different disorders. From February 2016 to December 2016 we used intra operative (OCT) in a diversity of neurosurgical procedures. The microscope integrated tool offers the possibility of quick, contact free sectional imaging and three dimensional imaging of tissue with a high spatial resolution of 7,5 micrometres. We here centre upon technical limitations, new possibilities and an improvement of intraoperative security in the future.

Keywords: OCT, spatial resolution, intraoperative realtime imaging, vascular neurosurgery, aneurysm

Intraoperative Imaging of Malignant Gliomas by Active Thermography

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Introduction
We employ thermography during craniotomy in order to discriminate cortical tissue in terms of its thermal properties. Infrared thermography is a non-invasive and white light independent method for intraoperative measurements of small temperature variations. The surface temperature of the exposed brain was measured by a highly sensitive infrared camera with a spectral range of 7.5-14 µm, thermal resolution of 30 mK at 30 °C and a spatial resolution of 170 µm per pixel at 20 cm object distance. The emitted heat radiation of the human brain can be regarded as superposition of various heat sources correlating with regional cerebral blood flow, metabolic processes as well as thermal properties of tissue like thermal conductivity. In prior work, we imaged the cortical blood flow by the application of a cold bolus applied through a central line. The main contribution of this study is a standardized representation of cortical tissue in terms of its thermal properties and an in-depth comparison to the present pathology.

Methods
The exposed cortex of patients with malignant glial and metastatic brain tumors who underwent craniotomy was recorded by time-resolved thermography. First, a NaCl solution of approx. 22 to 26 °C was applied to the exposed cortex. A temperature gradient is hereby projected into deeper tissue layers enabling us to unveil factors which contribute to the measured surface temperature distribution. The proposed machine learning framework further allows us to efficiently recognize the point in time this cooling event- and subsequent heating occurred. Second, the heating process was described by an established model of tissue heating. Finally, the model's time-decay constants yielded a standardized description of the imaged tissue in terms of its thermal properties. The findings were qualitatively validated by co-registration and fusion with a 3D model of the brain that was computed from the patient's preoperative MRI dataset.

Results
We provide a novel intraoperative workflow for the standardized characterization of malignant gliomas based on cold NaCl irrigations of the exposed cortex. Our machine learning framework achieves near real-time performance for the detection of these cortical irrigations. We found that the parameters describing the heating process correlate with tissue composition. Furthermore, the thermal properties associated with specific pathologies can be employed to discriminate gliomas and healthy tissue. In a significant number of cases we found a correlation between the potential tumor area inferred from the tissue's thermal properties and tumor sites found in preoperative MRI.

Discussion
The proposed method relies on the application of a cold NaCl solution to the exposed cerebral cortex. As this application is commonly done during neurosurgery, the method seamlessly integrates into current intraoperative workflows. The analysis of continuous thermographic imaging data of the exposed cortex by machine learning allows us to efficiently recognize the induced heating process and to estimate as well as visualize the thermal properties of the imaged tissue. The proposed methods and techniques could possibly provide neurosurgeons a standardized real-time

visualization of the thermal properties of brain tissue and by this yield valuable diagnostic information on the spatial extent of malignant gliomas.

Keywords: Neurosurgery, Intraoperative Thermal Imaging, Glioma Classification, Cold Bolus

Novel techniques to interrogate tumour-brain interface for enhanced intra-operative visualization and acoustics

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Introduction
For brain tumours, extent of resection has been shown to correlate with clinical outcome. A challenge prevails in dissecting the tumour-brain interface where it can become increasingly difficult to distinguish tumour from normal brain. Processes have been developed to identify abnormal cells through, i. a protein-specific contrast agent based on single domain antibodies (sdAbs) and MR sensitive nanoparticles, to visualize diseased cells, and ii. a cellular vibration profile to hear the sound of brain tumour.

Methods
i. Through llama immunization, we developed target specific sdAbs to EGFRvIII and IGFBP-7. The sdAbs were bioconjugated to Fe3O4 MR visible nanoparticles tagged with fluorescent markers for both IR and MR imaging. To investigate the sound of brain tumour, we used atomic force microscopy as an ultra-sensitive microphone. ii. A non-contact sensitive cantilever tip of the system detected vibration signature from both cultured cells and tissues, and brain tumour specimens. Root mean square of cellular fluctuations were recorded and their fast fourier transformation aligned the vibration signature along tumour specific frequency domain. These frequency clusters (below the audible range) were phase modulated with an audio frequency-shift keying method at baseband frequencies within the hearing range.

Results
i. We were able to successfully establish the process of developing novel target specific sdAbs, characterizing and sequencing them. The anti-brain tumour specific sdAbs were PEGylated to the silica-coated Fe3O4 nanoparticles. Visualization was successfully performed using both IR and MR technology using an established mouse model of glioma. ii. The Root mean square of cellular fluctuations was correlated to metabolism this feature could be used to differentiate between brain tumor cell lines in real-time. Malignant astrocytoma tissue vibrated with a much different frequency profile and amplitude, compared to meningioma or lateral temporal cortex. Vibration signals could be converted to sound waves in the frequency of human hearing, demonstrating, acoustic signatures unique to meningioma, malignant astrocytoma and neocortex.

Keywords: MRI, Glioma, Antibodies, Nanoparticles

LITT

Chairs: M Schulder, D Kacher, I Lee

Overview of MRI-Guided Laser Interstitial Thermal Therapy for Neurosurgical Applications

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MRI-Guided Laser Interstitial Thermal Therapy (MRgLITT) is a minimally invasive method for thermal destruction of benign or malignant tissue. MRgLITT entails targeted interstitial insertion of a cooled optical fiber to deliver laser energy in order to heat tissue in a controlled fashion, in conjunction with temperature monitoring based on MR imaging. The goal of such treatments is to heat targeted tissue to >60°C to cause coagulative necrosis, while sparing surrounding normal tissue and avoiding charring which occurs at temperature >100°C. This procedure can be an extension of a needle biopsy, utilizing the same trajectory.

Typically, surgeons use MRgLITT to target lesions <10 cm3 in order to limit mass effect from edema caused by the treatment. Indications include recurrent and difficult to access tumors (Norred 2014), epilepsy (Wicks 2016, Karsy 2016), and metastic tumors (Carpentier 2011) including progressive metastases after radiosurgery (Torcuator 2016). The sharp transition zone of the ablation makes LITT ideally suited for these applications.

In parallel with the first application of LITT for neurosurgical use (Sugiyama 1990) and the translation brain MRgLITT (Tracz 1992), MRI techniques for monitoring temperature (Jolesz 1988, Moki 1989) and targeting system and visualization techniques evolved (Kacher/ Nabavi 2001). This development culminated in early clinical use during 1990's (Asher 1992, Fan 1992, Kahn 1994, Kettenbach 1998). During this era, there was further refinement of temperature monitoring (Porter 1995) and translational research leading to a growing understanding of laser tissue interaction and correlation of thermal dose with histopathological analysis. Clinical application co-evolved.

Today, two system are commercially available for MRgLITT, with combined patient treatments numbering over 4,000 at ~140 different center. The Visualase (Medtronic Inc, Louisville CO USA) uses a diode laser operating at 980nm, whereas the NeuroBlate System (Monteris Medical, Plymouth, MN USA) utilizes a diode laser operating at 1064nm. The wavelengths are nearby one another on the same water peak of the absorption spectrum. Both systems utilize a targeting system the affixes to the skull, the AXiiS min stereotactic frame and the 3rd party Clearpoint (MRI Inteventions , Irvine, CA USA), respectively. Monteris and Clearpoint have software solutions for planning the trajectory to direct mechanical adjustments on the targeting device. Alternatively, more conventional neuro navigation systems can be employed for fiber placement. Monteris and Visualase offer solutions for head fixation on the MRI table and both harvest images from the MRI scanner during treatment to create a near real time theramal dose map overlayed on the grayscale images. Monteris offers a side firing fiber that can be can be manipulated with an actuator controlled from the work station in order to sculpt the thermal lesion. Visualase can automatically

halt treatment when the leading edge of the calculated thermal dose reaches the planned treatment volume.

A history, overview of the two commercial systems, and case studies will be presented.

Keywords: LITT, laser, MRgLITT, ablation, brain, tumor

Intra-operative imaging during insular laser ablation in children

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Introduction
Insular resection entails significant risk of injury to eloquent cortex, critical vasculature, operculum, internal capsule, and basal ganglia. Few pediatric series reporting outcomes after insular resection for epilepsy exist, so we are reporting our early experience employing an alternative procedure: "minimally invasive" stereotactic insular laser ablation under iMRI (intra-operative MRI) control in 7 children diagnosed with insular-onset seizures, some of whom had previously undergone open cortical resection. In our center, this surgical technique entails extensive use of the iMRI operative suite

Material and Methods
Over the past 24 months, we performed 150 epilepsy surgical procedures involving invasive monitoring, cortical resection, tumor resection, or laser ablation to address refractory focal onset seizures in 115 children (VNS procedures not included). Of the 34 children treated with iMRI controlled laser ablation, 7 (2 boys, 5 girls) required stereotactic insular ablation directed either by the Leksell frame or the ROSA robotic system. Age at seizure onset of these 7 patients ranged from 2.5 to 9 years (average 3.9). Age at time of ablation ranged from 4 to 18 years (average 12). Preoperative 3T MRI was normal ("nonlesional") in 3 children; preoperative imaging of the other patients disclosed dysplastic lesions congruent with seizure semiology and EEG findings. Four children had previously undergone cortical resection. Patients were observed in the neuro ICU overnight after ablation, then usually discharged the following day (average length of stay 1.3 days).

Results
Four children have maintained Engel Class 1 outcome at follow-up 5, 11, 13, and 17 months, respectively (one off all anticonvulsants); 2 patients remain Engel Class 2 at follow-up at 5 and 18 months, respectively. One patient has improved to Engel Class 3 at 11 months follow up. No child sustained a neurologic deficit related to laser ablation. Two of the children underwent insular ablation within the dominant hemisphere.

Conclusion
Intra-operative MRI is no longer limited to assessment of extent of resection. In our center, it also provides real-time feedback about thermal conditions of both target and surrounding neural tissue during intracranial laser ablative procedures. Intra-operative imaging facilitates laser ablation epilepsy surgery, rendering the hazardous and cumbersome transfer of patient and equipment between the operating room and the radiology department during surgery unnecessary.

Keywords: Pediatric, iMRI, LITT, Insula, Epilepsy

Laser Thermotherapy for Spinal Metastatic Disease in retrospective comparison to open surgery

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Introduction
While stereotactic radiosurgery can provide excellent control of spinal lesions, epidural disease in close proximity to the spinal cord limits the dose that can be administered to the tumor without delivering potentially toxic dose to the spinal cord. While traditional, open surgical approaches can create a safe margin around the spinal cord to enable high-dose SRS, such procedures can create significant morbidity as well as delay the initiation of other therapeutic modalities. Spinal laser interstitial thermotherapy (SLITT) has been introduced as a minimally invasive alternative of treating epidural disease and minimizing delay in return to systemic therapy. Early experience indicated the technique could provide local control with low morbidity. Comparison to standard surgical approaches is necessary to determine the utility of the procedure.

Methods
147 contemporaneously patients with metastatic epidural spinal cord compression treated at MD Anderson with open surgery (n=84) and SLITT (n=63) were selected for study. Medical records and imaging studies were analyzed and demographic data, anatomic location, ESCC scores before and after surgery, histology, morbidity from surgery, hospital LOS, days until further treatment, rate of local control and overall survival were retrospectively compared between the two groups.

Results
Overall patient demographics, clinical characteristics and tumor histologies were similar, except ESCC was higher in the surgery group as patients with impending of neurologic dysfunction were more often treated with traditional surgical apporaches. Compared to open surgery, SLITT was associated with smaller post-operative decrease in ESCC (1.3 vs 3.4 $P<0.0001$) but provided lower EBL (<100cc vs 1186cc $p<0.0001$) shorter hospital stay (3.4 vs 12.1 $p<0.0001$) less surgical morbidity (12.7 vs 28.6% $p=0.21$) and fewer days until treatment with XRT/SRS (1.8 vs 40.2 $p>0.0001$) and systemic treatment (21.7 vs 62.8 $p<0.0001$). Rates of local control and after one year and overall survival were similar between groups (PFS-1: 77.7 SLITT vs 80.4 open $p=.974$, Median OS 517 days SLITT vs 562 days open $p=0.839$)

Conclusion
Compared with open surgery, SLITT appears to offer comparative rates of local control while providing less surgical morbidity, shorter hospitalization and faster return to oncologic treatment. Additionally, the technique may be applicable to a broader set of patients with metastatic spinal disease who would not normally be candidates for surgery. These data provide further justification for a future randomized controlled comparison study currently being planned.

Keywords: LITT, spinal metastasis

Safety and Efficacy of MR-Guided Laser Interstitial Thermal Therapy Treatment of Recurrent High Grade Gliomas

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Introduction
High grade gliomas are highly aggressive tumors with a poor prognosis. With recurrence, treatment options become limited and the utility of open resection is controversial. Laser interstitial thermal therapy (LITT) offers a minimally invasive approach for cytoreduction without the morbidity of surgery. This study seeks to determine the efficacy of LITT in patients with recurrent high grade gliomas.

Methods
A single-arm, retrospective analysis for patients not eligible for any clinical trials at our academic undergoing LITT for tumor treatment at Henry Ford Hospital was conducted between November 2013 and April 2016. Those with biopsy-confirmed high grade gliomas were reviewed with attention to ablation volume, survival, and, demographic data. Imaging was performed at set intervals post-operatively.

Results
Twenty-two patients were identified with a total of 24 ablations. Pathology was Grade III glioma in 12 patients and Grade IV glioma in 10. On average, 72% of the pre-operative tumor volume was ablated. The immediate post-ablation volume was an average of 153% larger than pre-operative tumor volume. These increased to 224% around two weeks before dropping to 15% at 9 months. Decline in neurological exam was seen in 5 patients with persistent deficits in two. Average progression-free survival was 34.7 weeks, and average overall survival was 54.6 weeks.

Conclusion
The risk-benefit of surgical resection in recurrent high grade gliomas becomes difficult to assess given its poor prognosis. In this study, LITT was a safe and effective treatment for recurrent high grade gliomas in place of open resection with the potential to improve survival. Larger studies are needed to better determine complications and outcomes.

Keywords: laser interstitial thermal therapy, high grade gliomas, Magnetic resonance imaging-guided thermal therapy

MR-Guided Laser Interstitial Thermal Therapy in the Treatment of Recurrent Intracranial Meningiomas

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Introduction
Recurrent meningiomas can prove problematic for treatment, especially if anaplastic, as options are limited primarily to surgery and radiation therapy. Laser interstitial thermal therapy (LITT) is a minimally invasive technique for achieving immediate cytoreduction. This study seeks to determine the utility of LITT in the setting of recurrent meningiomas.

Methods
Patients undergoing LITT for tumor treatment at Henry Ford Hospital between November 2014 and February 2016 were identified. Those with biopsy-confirmed meningiomas were reviewed with attention to ablation volume, survival, demographic data, and complications. Imaging was performed at set intervals post-operatively.

Results
Four patients were identified, three of which had successful treatment with a total of four ablations. The one patient who did not have successful ablation was due to problems with stereotactically placing the laser catheter. One patient had a grade 1 meningioma, with the other two being Grade 3. Immediate ablation volumes were an average of 74% of pre-operative tumor volume. These increased to 91% at 2 weeks before dropping to 68% at 3 months. One patient had acute hemiparesis with speech difficulty, which resolved after six months. At date of last follow-up, two of three have had progression at average of nine weeks time, and two of three are still alive with average follow-up of 15 months.

Conclusion
In this study, LITT appears to be a potentially viable treatment for recurrent meningiomas. Ablation volumes did increase over time, but not beyond the initial meningioma volume Larger studies are needed to better determine complications and outcomes.

Keywords: laser interstitial thermal therapy, meningiomas, Magnetic resonance imaging-guided thermal therapy,

Phase I Trial of Safety and Efficacy of MR-Guided Laser Interstitial Thermal Therapy Treatment for Cerebral Radiation Necrosis

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Introduction
Cerebral radiation necrosis is a known complication of radiation therapy in up to 5% of patients. Treatment options are limited and include high-dose steroids, bevacizumab, and surgery. This study seeks to determine the safety and efficacy of LITT treatment for radiation necrosis.

Methods
In the prospective, phase I trial, patients underwent LITT for tumor treatment at Henry Ford Hospital between November 2013 and January 2016. Patients with biopsy-confirmed radiation necrosis were reviewed with attention to ablation volume, survival, demographic data, steroid dose, and complications. Imaging occurred at set intervals beginning one-two weeks post-ablation.

Results
Ten patients with 11 ablations were evaluated. Four patients had a primary diagnosis of high-grade glioma, while six were metastatic lesions. On average, 86% of the pre-LITT radiation necrosis volume was ablated. Immediate ablation volume increased to 220% of initial radiation necrosis volume, rising to 430% at one-two weeks before decreasing to 69% at greater than six months time. No patient had a decline in baseline neurological exam while inpatient. Four patients had a deficit after discharge. Three of those patients had worsening hemiparesis that improved to baseline over time. The fourth had intractable seizures without improvement. The 6-month survival was 77.8% and the 1-year survival was 64.8% based on Kaplan-Meier curve estimates.

Conclusion
In this prospective study, LITT was a safe and effective treatment for radiation necrosis with 90% of patients maintaining or returning to baseline neurological function. Despite an increase in the contrast-enhancing lesion volume by 430%, only one patient had a permanent deficit. Further studies are needed to better define the role of LITT in the treatment of cerebral radiation necrosis.

Keywords: laser interstitial thermal therapy, cerebral radiation necrosis, Magnetic resonance imaging-guided thermal therapy

Predictors of local control of post-stereotactic radiosurgery brain lesions treated with laser interstitial thermal ablation

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Introduction
MRI guided Laser Interstitial Thermal Therapy (MRgLITT) is a minimally invasive technique Thused to treat recurrent lesions after stereotactic radiosurgery (SRS) including radiation necrosis. Here, we identified factors associated with local control after treatment of recurrent post-SRS lesions with MRgLITT.

Methods
Thirty consecutive patients with 44 lesions who had signs of progressive disease were treated with MRgLITT. Volumetric analysis of pre- and post-treatment lesions was performed and the primary endpoint was local disease progression.

Results
The overall free progression survival time was 22.4 months. The local recurrence rate was 25%. Non-dural-based lesions had a median progression free survival time (PFST) of 24.4 (CI95% 27.7-21.1) months compared to 11.3 (CI95% 17-5.5) months for dural based lesions (p=0.015) The Cox Proportional Hazard Model showed a hazard ratio (HR) for recurrence in dural based lesions of 3.892 (1.185-12.787) (p=0.015). More completely ablated lesions had a PFST of 26.7 (CI95% 29.1-24.2) months compared to 4.5 (CI95% 6.4-2.7) months for incompletely ablated lesions (p<0.001). A completely ablated lesion presented a HR for recurrence of 0.42 (0.009 - 0.203) (p<0,001). A tumor/ablation volume ratio lower than 80% favored a longer PFST (24.3 months (95% CI 27.7-20.0) versus 15.2 (95% CI 23.1-7.4) months, CI 95%). The HR for recurrence in tumor/ablation ratio higher than 80% was 3.588 (1.086 - 11.861) (p=0.036). The volume of the tumor was a predictor of local recurrence with larger tumors (>5cm3) demonstrating a higher rate of local failure (p<0,001). The rate of local recurrence did not correlate with tumor histology. Deviation of the actual trajectory from the planned trajectory did not correlate with local failure. The median target deviation was 2.1mm +/- 1.23mm.

Conclusion
Local control of post-SRS lesions treated with LITT is dependent upon location (dural versus non dural), pre-treatment lesion size, and completeness of ablation. Smaller lesions with more complete tumor coverage demonstrated durable local control. Tumor/ablation ratio can be used to predict local recurrence. LITT demonstrated excellent safety and accuracy in deep lesions and is a good alternative to treat progressive disease after SRS for brain metastasis.

Keywords: Laser therapy, brain metastases, radiosurgery

Laser Interstitial Thermal Therapy for the Treatment of Intracranial Metastasis: An Evaluation of Pretreatment Tumor Features and Post-treatment Outcomes

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Purpose
To evaluate the imaging features of brain metastases treated with laser interstitial thermal therapy (LITT) at our institution in order to establish which characteristics may be helpful in predicting success or failure post-ablation.

Materials and Methods
A retrospective review was made of patients having undergone LITT for the treatment of brain metastases between August of 2013 and October of 2016. Thirty seven cases were collected for analysis. The following imaging characteristics prior to treatment were recorded: mass size, tumor histology, prior therapy, location of mass, tumor morphology and proportion of internal solid/cystic components. The patients' pre-treatment and follow-up imaging studies were reviewed to determine whether there was treatment response or tumor recurrence.

Results
A total of 13/37 patients showed a recurrent enhancing mass developing within a range of 3 months to over a year following ablation. Of these 13 patients, 6 required surgery for resection of enlarging masses. Pathology revealed viable tumor in 5/6 resected masses and 1 case of radiation necrosis. Of the 37 patients, 13 showed a favorable response to treatment with reduction in size of the masses on follow-up exams obtained at least 3 months following the procedure and in many cases up to 6 months later. In 11 of the cases the patients did not show clear response or progression and further observation is required. The most common primary tumors were breast (11/37), melanoma (10/37), and lung (9/37). No correlation was made between the primary histology and response to LITT. All patients had received treatment with gamma knife therapy, surgical resection or a combination of both prior to LITT. Preliminary results indicate that superficially located and dural-based masses have a higher tendency for treatment failure. Of the 13 patients who recurred, 5 had dural-based lesions and 5 were cortically-based, while the remaining 3 were either centrally located within the white matter or adjacent to ventricle. Conversely, of the 13 patients with favorable response only one was dural-based. The average pretreatment volume was 6.04cm^3, with tumor volumes that exceed 4cm^3 serving as a risk factor for postoperative tumor recurrence.

Conclusions
Lesions at locations known to be technically challenging for LITT (cortex and dura) and larger lesions have a higher tendency for recurrence. Knowledge of factors relevant to recurrence may enable improved patient selection for LITT.

Keywords: Laser therapy, metastases,

MRgLITT Induced Perfusion Changes Assessed by DCE-MRI

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Introduction
The purpose of this study is to investigate imaging biomarkers for assessing response to MR-guided laser-induced thermal therapy (MRgLITT) in brain tumors. Currently, 3D high-resolution post-treatment contrast-enhanced imaging provides a qualitative measure of the vasculature breakdown and empirical thermal dose estimates (CEM43, Arrhenius) are derived from the time-temperature history of the MR thermal imaging. This study presents findings in quantifying treatment induced tumor perfusion changes from dynamic contrast enhanced (DCE) imaging and correlates perfusion measurements with progression free survival.

Methods
The characteristic hyper intense region was used to define and segment the lesion volume on contrast enhanced T1W imaging pre- and post- therapy. Dynamic contrast MRI was used to quantify tumor perfusion. The initial area under the curve of the contrast uptake was measured at 60sec post bolus arrival (iAUC60). The discrete integral of the dynamic contrast uptake was computed using a trapezoidal rule at the acquisition time points and normalized by the average signal before the bolus arrival. Perioperative imaging was rigidly registered to compute the average iAUC60 in the target lesion volume, the treated lesion volume, and untreated tumor as well as measure the coverage. Progression free survival (PFS) was calculated from radiographic progression observed in follow-up imaging. Kaplan-Meier survival analysis and a log-rank test was performed to quantitatively compare the stratification of responders and non-responders based on the post treatment iAUC60.

Results
The mean tumor coverage (N=25) as measured by the Dice similarity coefficient (DSC) was 0.92. Average differences between perfusion imaging measurements in the region of interest outlining the target lesion (mean= 1.001) and in the treated tissue (mean=0.874) are statistically significant, $p<.05$, as measured by a paired sample t-test. Stratification of responders and non-responders by the median iAUC60 observed post treatment (median=.931, std=.25) showed significant difference in PFS of target lesions between responders and non-responders. Here, patients with an average iAUC60 greater than the median in a region of interest outlining the treated lesion are considered non-responders.

Conclusions
This study demonstrates the feasibility of quantitative image feature extraction from perioperative perfusion imaging to assess MRgLITT response. Verifying the quantitative image features in larger patient populations are needed to confirm results. The quantitative image features used are likely to provide additional inputs for multivariate automated classification of treatment response in on-going studies.

Keywords: Laser therapy, brain tumor

Use of real time thermography data during Laser Interstitial thermal therapy adjacent to eloquent white matter tracts- A preliminary experience

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Introduction

Laser interstitial thermal therapy (LITT) is a percutaneous minimally invasive procedure used in the treatment of both primary and metastatic brain tumors. MRI-guided LITT (MRgLITT) provides real-time intraoperative quantitative temperature maps and estimates the thermal ablation zone and has been increasingly used to treat deep-seated tumors. Diffusion tensor imaging (DTI) is an imaging technique used to assess the structure and integrity of white matter tracts. The combination of MRgLITT and real time DTI maps when treating brain lesions can provide safer and more extensive ablations.

Methods

Nine patients were treated with MRg LITT with tumors in close relation to eloquent white matter tracts. DTI data obtained was fused with LITT navigational images and the distance between white matter tracts (WMT) and the tumor margins were calculated. The extent of ablation (ablation cavity) was calculated by T1 subtraction scans. The distance between ablation cavity and WMT was calculated, as well as the temperature in proximity to the tracts during ablation. Neurological exam was record pre-operatively, on the first day post-procedure and on one month follow up.

Results

Of the 9 patients, 6 had a Glioblastoma multiforme (GBM), two patients with oligoastrocytoma (OA), and one patient with metastatic disease following recurrence after stereotactic radiosurgery. The mean tumor volume was 7.72 cm3, the mean ablation volume was 10.65cm3. Complete ablation was achieved in 2 patients. The mean untreated volume was 0.89cm3. Seven patients had lesions located near corticolspinal tract (CST) and 2 had lesions on the left hemisphere in close proximity to the arcuate fasciculus (AF). The mean distance between the tumor and white matter tracts (WMT) was 2.8mm (Range 0.5mm to9mm) and from the ablation cavity to WMT was 1.7mm (Range 0 to 11mm). Six patients experienced mild worsening neurological deficits after LITT, with 3 of them returning to their preoperative state at one month follow up. In these 6 patients, five had the ablation cavity overlapping partially the WMT with temperature recordings adjacent to the tracts between 41 and 55 °C. Those patients who presented with persistent mild neurological deficits had temperatures range between 44 and 55 degrees °C. Of the 4 patients where the ablation cavity partially overlapped the CST, all of them presented with mild post-operative deficits, one with transient deficit (temperature of 41 °C on the CST) and three with permanent mild worsening compared to pre-operative baseline (temperatures of 44 to 55 °C on CST). Patients who had pre-operative deficits were prone to have worse neurological outcomes after LITT (4 out of 6 patients). In the majority of cases (8 patients) the use of DTI during the procedure influenced the ablation extent guiding the trajectory and the use of side fire to prevent damages to WMT.

Conclusion

Overlap between ablation cavity and WMT can result in postoperative deficits. Temperatures above 44 °C adjacent to WMT correlated with new postoperative deficits. The association of real time temperature maps and DTI tractography during MRgLITT procedures helps better planning and minimizing significant injury to the WMT.

Keywords: Brain tumor, Diffusion tensor imaging, Laser therapy

Special MR-Applications

Chair: M Tatagiba, V. Paterno, J Honeycut

Non-Pituitary and Non-glioma indications for iMRI

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Intraoperative High-field Magnetic Resonance Imaging and Multi-modal Neuronavigation Guided Surgery for Patients with Low-grade Temporal Lobe Glioma and Epilepsy

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Objective
The aim of this study is to investigate the role of intra-operative MR imaging in temporal lobe low grade glioma (LGG) surgery and to report the surgical outcome in our series with regard to seizures, neurological defects, and quality of life.

Methods
Patients with temporal lobe non-enhancing gliomas who presented with seizures in the course of their disease were enrolled in our prospective study. We non-randomly assigned patients to undergo intra-operative magnetic resonance imaging (iMRI)-guided surgery or conventional micro-surgery. Extent of resection (EOR) and surgical outcomes were compared between the two groups. The post-operative neurological deficits were recorded. And survey for the health related quality of life of the patients, were conducted and analyzed.

Results
Forty-one patients were analyzed in the iMRI group, and 14 were in the conventional group. Comparable EOR was achieved for the two groups ($p = 0.634$) although preoperative tumor volumes were significantly larger for the iMRI group. Seizure outcome tended to be better for the iMRI group (Engel class I achieved for 89.7 % (35/39) vs 75 % (9/12)), although this difference was not statistically different. Newly developed neurological deficits were observed in four patients (10.3 %) in iMRI group and two patients (16.7 %) in control group, respectively ($p = 0.928$). Free of seizures and neurological morbidity led to a return-to-work or return-to-school rate of 84.6 % (33/39) in iMRI group vs 75 % (9/12) in control group, respectively ($p = 0.741$).

Conclusions
Our study provided evidence that iMRI could be a safe and useful tool in temporal lobe LGG surgery. Optimal extent of resection contributed to favorable seizure outcome in our series with low morbidity rate, which led to a higher return-to-work rate. A larger cohort, randomized trial is needed to verify the real role of iMRI for the surgical management of temporal lobe LGGs.

Keywords: Low-grade glioma, lesional temporal lobe epilepsy, intra-operative magnetic resonance imaging

iMRI in STH adenomas

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The effect of intraoperative MRI (iMRI) on the extent of sellar region tumors treated endonasally has been described in previous research. However, the effects of iMRI on endocrinological outcome of growth hormone (GH)-secreting adenomas have been studied in only a few small cohort studies.

Method
Inclusion criteria were: primary transsphenoidal surgery for GH-secreting adenoma from January 2009 to December 2014, a minimum follow-up of 1 year, complete endocrinological data, at least one iMRI and at least two postoperative MRIs. The cohort consisted of 105 patients (54 females, 51 males) with a mean age of 48.3 years (range 7-77 years). There were 16 microadenomas and 89 macroadenomas.

Results
Endocrinological remission in the whole cohort was achieved in 64 (60.9%) of the patients. Resection after iMRI was attempted in 22 (20.9%) of the cases.

Resection after iMRI led to hormonal remission in 9 (8,6%) cases.

Endocrinological postoperative deficit was observed in 10 cases (12.5%). Postoperative cerebrospinal fluid leakage indicated the necessity to reoperate in three cases (3.8%). No neurological deterioration was observed.

Conclusions
iMRI not only influences the morphological extent of pituitary adenomas resection but also the endocrinological results. We encourage the routine application of iMRI in pituitary adenoma surgery, including hormone secreting pituitary tumors.

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Keywords: iMRI, transsphenoidal surgery; acromegaly

Endoscopic versus microsurgical resection with intraoperative MRI in transsphenoidal pituitary adenoma resection

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Object
Endoscopic approach helps to achieve good visualization of the sella in transnasal transsphenoidal pituitary surgery. We have compared the added value of iMRI for extent of resection in endoscopic microsurgical transsphenoidal adenomectomy and compared it to microsurgical approach.

Methods
A total of 96 patients with pituitary adenoma were enclosed. 28 consecutive patients underwent endoscopic transnasal transsphenoidal tumor resection. Historic cohort of 68 consecutive patients treated microsurgically were analyzed for the evaluation. Knosp classification was used to stratify the invasive growth pattern of adenomas in cavernous sinus. Tumor volume in intraoperative MRI as well as in the first follow-up were analyzed. Demographic data, clinical symptoms, complications as well as pituitary function were evaluated. Mann-Whitney-U, Fisher exact test and binary logistic regression were used for analysis.

Results
The most common histological subtype was non-functioning adenoma (N=65, 67.7%). There were significantly less additional resections after conducting iMRI in the endoscopic group in Knosp 0-2 adenomas (microsurgical 16/34, 47.1%, endoscopic 2/15, 13.3%, p=0.029). No significant difference was found in Knosp 3-4 adenomas (microsurgical 20/34, 58.8%, endoscopic 6/13, 46.2%, p=0.520). The use of endoscopic approach was associated with smaller intraoperative tumor volume (p=0.023). No significant difference was noted with regard to surgical complications between both cohorts. Endoscopic approach was significantly associated with satisfactory endocrinological outcome (p=0.001).

Conclusion
In endoscopic transsphenoidal resection of pituitary adenomas graded Knosp 0-2 iMRI can detect residual tumor in only rare cases. In invasive adenomas with infiltration of cavernous sinus graded Knosp 3-4 with suprasellar or parasellar extension additional tumor resection and less residual tumor volume has been achieved by using iMRI in both groups. Endoscopic approach might lead to better endocrine outcomes.

Keywords: endoscopic transsphenoidal surgery, intraoperative MRI, pituitary adenoma, tumor volume

iMRI in Pediatric Neurosurgery

Chair: M Kirsch, D Orringer, S Prabhu

Aborted intraoperative MR imaging during pediatric neurosurgical procedures: causes and frequency

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Introduction
Although intraoperative magnetic resonance imaging (iMRI) capability has become an integral part of our pediatric neurosurgery program technical setbacks associated with the imaging procedure do occasionally occur. We analyzed the frequency and factors giving rise to aborted iMRI imaging during neurosurgical procedures in our hospital.

Methods
We retrospectively reviewed all neurosurgical cases performed in our hospital from 2006 through 2016. Completed neurosurgical cases scheduled as "iMRI cases" were included in this review. Data was collected using an IRB approved multicenter iMRI database (iMIND).

Results
Our review disclosed 795 iMRI procedures. Attempted iMRI imaging was abandoned in 33. Reasons given for aborting included: patient-scanner incompatibility in 10 (obesity 7, patient position 3); iMRI room technical issues in 9 (scan artifact / coil malfunction 3, bed malfunction 2, MRI scanner malfunction 2, power failure 1, scanner door malfunction 1); observance of CSF leak during attempted dural splitting Chiari procedure in 7; surgeon decision not to scan in 6 (acceptance of known incomplete tumor resection 3, medically unstable patient 3), and possible presence of unaccounted angiocath from anesthesia induction 1.

Conclusion
In our institution iMRI remains an integral tool for pediatric operative management of tumors, epilepsy, and Chiari I malformations. The frequency of events leading to abandoning intraoperative MR imaging (4.2%) proved unexpectedly high. This information should prove useful to assessing benefits/liabilities of iMRI systems and properly inform patients' and families' expectations.

Keywords: iMRI, pediatric, aborted cases, tumor, Chiari, epilepsy

Application of high-field intraoperative magnetic resonance imaging in pediatric Neurosurgery

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Introduction
We study the safety, advantages and limitations of high field iMRI for cranial neurosurgical procedures in children with particular attention to craniopharyngiomas and gliomas.

Methods
We performed 82 surgical procedures in pediatric patients (range 0.8 - 15 years) over an 8-year period (2007-2014) using iMRI. The children were divided in 3 groups: sellar region tumors (group 1), gliomas (group 2), and other pathological entities (group 3). Pre- and postoperative neurological status, presence of residual tumor, number of intraoperative scans and complications were evaluated.

Results
In group 1 gross total removal (GTR) was performed in 22 (88%) and subtotal removal (STR) in 3 (12%) cases. In group 2 GTR, STR and partial removal (PR) were obtained respectively in 15 (56%), 7 (26%) and 5 (18%) procedures. In group 3 a GTR was carried out in 28 (93%) and STR in 2 (7%) patients. In craniopharyngioma (group 1) and glioma (group 2) cases where a complete removal was planned the iMRI imaging allowed to localize residual lesion and reach the surgical goal through further resection respectively in 18% and 27% of the procedures. Moreover, in gliomas the resection could be extended from partial to subtotal in 50% of the cases. In 17% of the patients belonging to group 3 iMRI enabled the identification and further removal of tumor remnants.

Conclusions
The iMRI was most effective in increasing the tumor´s extent of resection especially in patients affected by low-grade gliomas and cranipharyngiomas. Theobserved disadvantage of high-field iMRI was the limitation in terms of operative positioning due to the configuration of the surgical table.

Keywords: intraoperative MRI, glioma, craniopharyngioma

Pediatric Stereotactic Procedures with ClearPoint Intraoperative Magnetic Resonance Imaging (iMRI)

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Introduction
ClearPoint (MRI Interventions) is a real time stereotactic guidance system used in the MRI / iMRI suite to ensure accurate placement of biopsy needles, catheters or electrodes. The system has been used in our 1.5 Tesla iMRI (IMRIS) operating suite over the last three years for iMRI deep brain stimulator (DBS) placement, needle biopsies, and / or laser interstitial ablation (LIT) (Visualase Medtronic).

Methods
A retrospective review of surgical cases was reviewed over the last three years. Data was collected using an IRB approved multicenter iMRI database (iMIND). All cases were performed at Cook Children's Hospital.

Results
44 stereotactic iMRI procedures (28 DBS, 6 needle biopsy, 5 LIT, 5 combo biopsy/LIT) were performed from November 2013 to November 2016 (36 months). Average 2D radial error (average of x and y coordinate errors) was 0.59 mm. (DBS 0.46, biopsy 1.2, LIT 1.36, combo biopsy/LIT.56). There was one complication of epidural hematoma from pin placement before the operation had begun. This complication was exacerbated by use of a rigid coil. There has also been one DBS infection and one symptomatic intracerebral hemorrhage from needle biopsy. Average total room time was 4 hours 10 minutes.

Conclusions
ClearPoint is a real-time MRI guided stereotactic system that provides safe extremely accurate placement of neurosurgical equipment. This has allowed our DBS patients to undergo general anesthesia while ensuring accurate lead placement. Due to small head sizes, it is essential to have a flexible MRI coil to maximize operating space and to minimize complications. ClearPoint has become an invaluable tool in my enlarging stereotactic practice.

Keywords: iMRI, Stereotactic, ClearPoint, deep brain stimulation (DBS), Needle Biopsy, laser interstitial ablation, pediatric

MR-OR-Designs and Set-Up

Chairs: Y. Muragaki, M Giordano, M Maldaun

Image Guided Surgery and Interventional Radiology in the AMIGO Suite

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“Next Room” Intraoperative Magnetic Resonance Imaging for Awake Craniotomy – Preliminary Experience and Technical Note

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During gliomas surgery “maximal safe resection” must be the main goal.

Intra-operative Magnetic Resonance Imaging (iMRI) associated with Awake Craniotomy (AC) is a valuable tool in order to achieve this objective. The AC with a “next-room” iMRI concept will be described in a stepwise protocol.

Retrospective analyses of 25 patients submitted to AC using iMRI is presented and a stepwise protocol discussed.

The mean age was 41.7 yr. 88 percent of the tumors were located in the left hemisphere. All tumors were near or within eloquent areas. Fifty-two percent of the cases were glioblastomas multiforme and 48% of the patients had a low grade gliomas. The mean surgical time and iMRI time were 4h4min and 30 min respectively. New resection was performed in 33% after iMRI. Extention of resection (EOR) higher than 95% was possible in 66.7%. The main reason of EOR lower than 95% was positive mapping of eloquent areas (9 patients). 7 patients presented clinical worsened after surgery, 6 of them had GBM but all of them improved after 30 days. We had 1 case of infection after surgery.

Monthly the MRI scan almost 600 patients and is used generally in 4 cases as iMRI. This showed a good investment instead the higher cost of a brain suit. Combining AC with “next-room” iMRI is a complex procedure but if performed using meticulous technique may improve the overall tumor resection and is safety of the patient, representing the maximal safe resection concept.

Keywords: awake craniotomy, intra-operative MRI, maximal safe resection , glioma surgery

The Impact of Intraoperative Magnetic Resonance Imaging (iMRI) In A Community Hospital: A Retrospective Review of Cases From 2006-2016

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Introduction
Intraoperative magnetic resonance imaging (iMRI) has become a major development in the field of neurosurgery. While used mostly in academic institutions, iMRI is uncommon in community hospitals. This study measures the effectiveness of iMRI in one community hospital by examining all operations using this technology between 2006 and 2016. Because of the known effectiveness of intraoperative MRI on treatment of malignant gliomas, cases in which pathology revealed glioblastoma multiforme (GBM) were analyzed separately.

Method
The intra-operative MRI database for Wilkes Barre General Hospital was reviewed and categorized by type of surgery. For cases identified as GBM, length of survival was measured then stratified by age, gender and location of the tumor.

Results
A total of 248 surgeries that used intraoperative MR imaging were performed between June, 2006 and August, 2016. The majority were either for tumor resection or guidance for stereotactic biopsies (121). Imaging after a cervical decompression was the next most common procedure (114). These became less frequent over time. Treatment of vascular pathology (13) also became less frequent over time. As a subset of craniotomies, intra operative guidance for Chiari decompression (6) became more prominent in recent years. In 2009, 46 intraoperative MRI surgeries were performed. Operations declined since then. Only 9 were performed in 2015. For GBM surgeries, information from the intraoperative MRI led to additional tumor resection in 12 of 28 surgeries (42.9%). The average length of survival for these patients was 28.4 months. The average length of survival in patients with no additional tumor resected was 14.0 months. An unpaired one-tailed test revealed a p-value of 0.059.

Conclusion
Over time, there was a marked decrease in the total number of iMRI cases being performed. This may have been from increasingly selective indications. Physicians may have preferred imaging patients with neoplasms and other pathologies where iMRI could change surgical decision making. With respect to GBMs, even though the difference did not reach statistical significance, use of an iMRI appeared to improve survival in a select group of patients. This implies that even in a community setting, intraoperative imaging improves the extent of surgical resection of tumors.

Keywords: Multiphoton microscopy, regeneration, alginate-hydrogel, axolotl

Development of the optimal MRI protocol for preoperative planning and intraoperative assessment of glioma resection and biopsy

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Introduction
A magnetic resonance imaging (MRI) is undeniably the gold standard for the diagnosis and surgical treatment planning of brain gliomas. The wealth and diversity of scanning modalities let to biologically characterize the tumor already at the imaging stage, bringing the knowledge about its topological and structural heterogeneity, allowing to plan the therapy and assume prognosis for the individual patient. Gathering all that information on every stage of the disease would be a therapeutic ideal. However, the clinical reality induces, or even forces a choice of information which is essentially required for a precise and safe surgical approach. In this study, we aimed to develop the optimal 1.5 Tesla MRI protocol that gathers the biological information about the tumor and allows to successfully plan glioma resection or biopsy.

Methods
In a 2-year period over 50 consecutive patients with brain gliomas were examined using extended preoperative diagnostic protocol, including sequences: T1-weighted, T2-weighted, fluid-attenuated inversion recovery (FLAIR), susceptibility-weighted imaging (SWI), diffusion-weighted imaging (DWI), diffusion-tensor imaging (DTI), time of flight (TOF), perfusion-weighted imaging (PWI). The MRI findings were judged as for tumor heterogeneity, delineation, vasculature, bleeding and necrosis, infiltration of adjacent and far structures, as well as destruction of corticospinal tracts. The surgical approach was planned initially using T1W and T2W images, and then the other sequences were consecutively added with the notice whether and how they objectively influenced the approach. The intraoperative MRI was done with T1W and FLAIR sequences using DWI, where applicable. The postoperative control of extent of resection was done with T1W, T2W, FLAIR and PWI sequences <72 hours after surgery. The observations were then compared with patients' clinical course and histopathological diagnosis.

Results
The study showed that all the included sequences added information to the planning procedure, and complemented the tumor picture that then correlated with molecular and pathological data and course of the disease. Especially SWI and DTI, which are not included in standard diagnostic protocol in our hospital, were found to be very informative and changing the surgical approach.

Discussion
MRI findings strongly correlate with intraoperative tumor features and serve as a basic tool when planning surgery. It appears that it can serve also as a single monitoring tool for guiding tumor resection extent. The inability to exclude any of the sequences from the protocol as less useful shows that we should further extend our protocols, rather than reducing them. Although the complete information of the tumor is wanted on every therapeutic stage, the wide initial imaging diagnostics describes the native tumor state and correlates best with pathological diagnosis and further prognosis.

Keywords: glioma, MRI protocol, intraoperative MRI, surgical planning

Intraoperative MRI, when to use it?

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Introduction
Intraoperative MRI (ioMRI) has been demonstrated as useful and safety tool in Neurosurgery, not only for brain tumors resection, but also in brain biopsies, epilepsy and vascular surgery. Once the neurosurgeon has this equipment in the theater, is he/she using it in every case?

Material and Methods
We analyzed all the ioMRI performed in our department during the first year and the reasons why the ioMRI were done. The cases excluded for the ioMRI were also studied.

Results
The ioMRI unit was installed in our department in January 2016, from then until December 2016, all the patients with brain tumors were possible candidates for its used. The patients with poor clinical status or incompatible positioning for MRI were excluded for ioMRI. Monitoring and awake surgery were not a limitation of the procedure. However, it was time consuming and we were not able to conduct two procedures during the same day.

Conclusion
Based on our one-year experience with the ioMRI, we discuss different situations where the neurosurgeon must decide if the extra cost and time of the ioMRI is justified and how the cases are selected for ioMRI.

Keywords: indications for intraoperative MRI, brain tumors

Feasibility, initial results and future aspects of intraoperative resting-state fMRI

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Introduction

Intraoperative resting-state fMRI (iRS-fMRI) feasibility has been described by our group for the first time. The intraoperative use of RS-fMRI might offer an entirely new approach for intraoperative monitoring and preservation of patients' neurological function during brain-surgery in eloquent areas. This is to describe current developments in working with iRS-fMRI especially for the sensorimotor network in patients with lesions in or directly adjacent to the central region and/or pyramidal tract. The current status and results of our research and possible future developments are described and discussed.

Methods

Twenty patients were examined to prove feasibility of iRS-fMRI in the rather stable auditory network. Successful analysis led to the further analysis of twelve patients undergoing iMRI-guided resection of lesions in or directly adjacent to the central region and/or pyramidal tract. iRS-fMRI was performed pre- and intraoperatively and correlated with patients' postoperative clinical condition, as well as with intraoperative monitoring (IOM) results. Independent component analysis (ICA) was used to post-process the RS-fMRI data concerning the sensorimotor networks.

Results

iRS-fMRI with anesthetized patients proved to be feasible for the auditory network. ICA of the second cohort with lesion in or directly adjacent to the central region and/or pyramidal tract was evaluated and correlated with clinical findings. Results of ICA of the sensorimotor network revealed comparable preoperative z-scores between hemispheres, significant decrease of z-scores ($P<0.01$) was shown in patients with new neurological deficits postoperatively. The ipsilateral intraoperative z-score had a significant negative correlation with the degree of paresis immediately after the operation ($r=-0.67$, $P=0.0001$) and at the day of discharge from the hospital ($r=-0.65$, $P=0.0001$). ROC curve analysis demonstrated moderate prognostic value of the intraoperative z-score (AUC: 0.84) for the paresis score at patient discharge. The activation of the sensorimotor areas in the contralateral hemisphere did not demonstrate any significant difference before and after operation and was not correlated with the degree of paresis.

Discussion

The use of iRS-fMRI with ICA is feasible and the results may correlate with clinical parameters demonstrating a significant negative correlation between the intensity of the iRS-fMRI signal and the postoperative neurological changes. Future efforts need to be towards a further analysis and development of this technology. If a prove of this concept might be accomplished in a controlled trial, the use of intraoperative MRI might gain a new field of application. Such a possible momentum might enable technological developments in cooperation with industrial partners to develop software algorithms for an accelerated online analysis of iRS-fMRI data in the operating theatre.

Keywords: iMRI, RS fMRI

Stereotactic accuracy of a compact, mobile intraoperative MRI

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Introduction
We compared the stereotactic accuracy of a new compact intraoperative MRI (iMRI) based on a 0.15 Tesla (T) magnet to both standard surgical navigation on a 1.5T diagnostic scan MRI and to navigation with an earlier model of the same system.

Methods
The accuracy of each system was assessed using a water-filled phantom model of the brain. The phantom was scanned in the operating room (OR) while positioned in the center of the magnetic field (COF) or periphery of the magnetic field (POF) of the new system. Scans were obtained using T1-weighted (W), T2W, PSIF, and FLAIR sequences. Data were compared to those obtained in a previous study assessing the older system. Additionally, the stereotactic accuracy of the new iMRI was measured against that of standard surgical navigation on a 1.5T diagnostic scan MRI using T1W images (with the same water phantom).

Results
Navigation with iMRI was more accurate than that using diagnostic MRI. Mean error with the iMRI using T1W images was 1.24 0.47 mm and 1.28 0.49 mm with T2W images, versus 2.43 0.81 mm for navigation based on T1W images from the 1.5T scan (95% CI, $p = 0.016$ and 0.001, respectively). In addition, we found that T2W images from the newer iMRI yielded a lower navigation error than those acquired with the prior model, 1.28 0.49 mm vs. 3.15 0.63 mm at the 95% CI, $p < 0.0001$. The higher degree of accuracy with iMRI-based navigation may reflect the ability to bypass the registration that is needed when employing a scan acquired preoperatively, a step that introduces another source of error into the process.

Discussion
A high degree of stereotactic accuracy can be achieved with a compact, low field iMR imager. Improvements in magnet design can yield progressive increases in accuracy, validating the concept of these devices designed for use during intracranial surgery. Avoiding the need for registration between image and surgical space also can increase navigation accuracy.

Keywords: iMRI, stereotactic, neuronavigation

Intra-paraventricular tumors: role of high-field intraopMRI

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Introduction
The usefulness of high-field intraop MR imaging as resection control is well established in patients with gliomas and other brain tumors, such as pituitary adenomas. In this study we aimed to evaluate its role in surgery of ventricular and paraventricular tumors.

Methods
Retrospective study of the patients with ventricular and paraventricular tumors operated consecutively in the INI BrainSuite since its establishment in 2007. The number of intraoperative image acquisitions and the presence of tumor remnants at these studies were noted. According to the findings the tumors were divided in 2 subgroups: Group A, in which the surgery was continued after the intraop imaging because unexpected remnants were visualized that could be safely removed; and Group B, in which the surgery was discontinued either because the tumor was removed completely or the remnants were regarded as unremovable due to their location. The histopathological findings were correlated to the usefulness of the intraop MRI.

Results
One intraop image acquisition at the end of surgery was performed in the patients with subependymomas, subependymal giant cell astrocytomes, colloid cysts and craniopharyngiomas. It proved that the goal of surgery has been achieved: the tumor was either completely removed or the rest could not be removed safely. More than one image acquisitions were performed in case of astrocytomas, ependymomas and central neurocytomas in order to: update the functional and morphological dataset, to assess the surgical progress (estimate the extent of resection, intraop orientation, distance to vital structures), or for resection control.

Discussion
The benefit of performing intraop MRI control in patients with ventricular/ paraventricular tumors depends on their pathological type. It is essential in achieving the goals of surgery in astrocytomas, ependymomas and central neurocytomas, while in other tumors, such as subependymomas, subependymal giant cell astrocytomes, colloid cysts and craniopharyngiomas, it might be regarded just as early postoperative imaging control.

Keywords: intraoperative MRI, ventricular tumor, paraventricular tumor, central neurocytoma

Image-based Intraoperative Holographic Long-distance Telecollaboration during Neuro-endoscopic Procedures with Head-mounted Display Devices

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Background
Novel technologies which can geographically extend the capabilities of individual surgeons and enable real-time, long-distance telecollaboration has great potential for both clinical and educational applications. The authors have developed a head-mounted holographic display system that allows remote participants to simultaneously view a shared field of view for real-time surgical telecollaboration during neuro-endoscopic procedures.

Methods
The authors demonstrate the capability of head-mounted holographic display devices to facilitate long-distance telecollaboration during endoscopic procedures in 30 cases. The system consists of local and remote devices (Hololens, Microsoft Corp.) with integrated video capture devices and video displays. Each device mutually connects via Internet, allowing long-distance point-to-point communication. Software (Skype preview for Hololens) composites the local video feeds and holographic markers, displaying a hybrid perspective to each participant. Local and remote test sites were situated in Beijing and Nanchang city, respectively. Endoscopic ventriculostomy was used for subjective and objective evaluation of system performance. Task and system performance were subjectively evaluated, while additional video analysis was used for objective assessment of delay and resolution.

Results
Head-mounted Hololens allowed both surgeons to engage in complex visual and verbal communication during the procedure. Analysis of 30 video clips revealed video delay of 300 milliseconds (range, 100-520 milliseconds) relative to the audio signal. Excellent image resolution allowed the remote neurosurgeon to visualize all critical anatomy. Holographic markers can be added on the video image intra-operatively. Both neurosurgeons could gesture to structures with no detectable difference in accuracy between stations. Thirty endoscopic procedures have been performed with the use of Hololens between two cities, with no significant complications.

Conclusion
Wearable holographic display technologies that allow long-distance, intraoperative guidance, and telecollaboration have great potential. Hololens, with proper software may be an inexpensive, feasible solution for real-time, long-distance telecollaboration of neuro-endoscopic procedures. Delay, image quality, and dedicated software are factors that require further optimization, but are within the realm of current technology. This technology potentially enables experts to mentor remotely located less experienced personnel, who may practice in rural area or across different counties.

Keywords: image-based, holographic imaging, endoscopy, telecollaboration

Intra-operative Mixed Reality Hologram Guided Neurosurgery: Technical Note

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Objective
To develop and evaluate the technical feasibility and clinical experience of an intra-operative mixed reality holographic head-mounted system for intra-operative localization during intracranial lesion resection and endoscope insertion.

Methods
An intra-operative mixed reality holographic head-mounted system was developed using the Microsoft Hololens platform. Multimodal imaging datasets, including MRI and CT images was used for lesion segmentation and three-dimensional (3D) modeling. Open-source software (3D Slicer) was used to generate 3D models of lesions or ventricles. The models were then converted to FBX files with third-party software (Paraview). The FBX files were then imported into Hololens and displayed with Hololens APP (3D Viewer beta). Intra-operatively, the hologram of the lesions and markers were displayed in a mixed reality fashion, and were then adjusted until coincided well with the actual markers or anatomical landmarks, so that the hologram of the lesions can be overlapped in the actual surgical field. Furthermore, the hologram can be restored intra-operatively, so that the intra-operative localization of lesions can be feasible after craniotomy. Twenty-one cases who had intracranial lesion resection or endoscopic procedure were enrolled into this study. In all cases, a standard neuro-navigation system was used to compare and measure the error of holographic localization.

Results
In all cases, intra-operative hologram based procedures were successfully achieved. Mixed holographic simulation was useful for preoperative surgical rehearsal and intra-operative intervention. The median error between standard neuro-navigation and holographic localization is 6mm (range from 2mm to 10mm).

Conclusion
The intra-operative mixed reality holographic system is technically feasible. The accuracy of this system for intra-operative localization of intracranial lesions or ventricles is acceptable. However, dedicated software is needed for easier and more accurate implement of this novel system. And larger cohort controlled study is warranted to evaluate the accuracy and validity of this system.

Keywords: Mixed reality, hologram, multimodal imaging, neurosurgery