Purpose
The purpose of this study was to investigate how intraoperative MRI can help to improve the extent of a resection in neurosurgical procedures.

Introduction
Our concept is based on the installation of a low-field MR-scanner in a ‘twin’ operating theatre in combination with two neuronavigation systems. Intraoperative MRI is used to evaluate the tumor resection, providing the possibility of a second look, and to allow intraoperative image update for neuronavigation to compensate brain shift.

Methods
We performed intraoperative MRI in 161 patients using a 0.2 Tesla Magnetom Open (Siemes AG, Erlangen, Germany), which is located in the radiofrequency shielded part of our ‘twin’ operating theatre.

In brain tumor surgery (n=54) (46 cases of glioma located around eloquent areas and 8 cases of tumors in the lateral or third ventricle e.g. neurocytoma or subependymoma) and in surgery for temporal lobe epilepsy (n=35) the patient is operated in the conventional part of the ‘twin’-OR and transported into the scanner on an air-cushioned OR table. A 3D-FLASH (fast low angle shot) sequence (slab thickness: 168 mm, slice thickness: 1.5 mm, TR: 16 ms, TE: 7 ms, FOV: 250 mm) was used for imaging, allowing image data update for neuro-navigation. Contrast agent (Gadolinium-DTPA) was applied if the tumor showed enhancement in the preoperative pictures. In selected cases, as low grade astrocytomas, a T2-weighted sequence (slice thickness: 3 mm, 19 slices, TR: 6000 ms, TE: 117 ms, FOV: 230 mm) was performed additionally.

For intraoperative update of neuronavigation bone fiducials were attached around the craniotomy, allowing intraoperative registration of the new image data. The intraoperative image data were transferred to the navigation system (MKM microscope, Zeiss, Oberkochen, Germany) via ethernet.

Pituitary adenoma and craniopharyngioma micro-surgery (n=43) with MR-compatible equipment was performed on the movable table of the MR scanner in the MR-Suite itself. Coronal and sagittal oriented scans (T1-weighted, slice thickness: 3 mm, TR: 340ms, TE: 26ms, FOV: 200mm) were obtained after 8 minutes each.

In 28 patients resection control was performed for other lesions, such as cavernoma, cysts, etc.

Results
In brain tumor surgery (gliomas and ventricular tumors) intraoperative resection control showed significant tumor remnants in nearly half of all patients. In 12 patients tumor resection was completed by a second look, guided with additional information by an update of neuronavigation. In 13 patients remaining tumor could be documented, but no further removal was performed due to infiltration of eloquent brain areas (e.g. motor strip, speech area), as well as especially in the glioblastoma cases due to the biology of the tumor. In the low grade glioma (grade I & II) the rate of complete resection could be increased from 56% to 82%.

In temporal lobe epilepsy surgery (n=35) intraoperative MRI could document the extent of the neocortical and mesial resection, which was individually tailored, as well as it could prove the complete excision of the lesion in the non-cryptogenic cases.

In surgery of suprasellar tumors the extent of resection of the intracranial tumor part could already be documented intraoperatively. In the majority of these cases this ultra-early result matched the late MR-result, which normally is obtainable without artifacts not earlier than 2-3 months postoperatively.

Discussion
Our preliminary experience suggests that intraoperative MRI is a convenient tool to evaluate the extent of resection intraoperatively, offering the possibility of a second look. Additionally in complicated cases there is the possibility to update the neuronavigation system with intraoperative image data to compensate the effects of tumor removal and brain shift.

Interpretation of intraoperative MRI is complicated by artifacts which may be caused by external influences such as the anesthesia equipment and the whole electrical environment, by intrinsic factors such as an instability of the magnetic field, and third by the operative field itself i.e. the brain-air-barrier and the usage of a drill. The interpretation of the imaged brain-tissue is complicated furthermore by the differential diagnosis of tumor remnant, normal brain, blood, contrast medium, disturbed blood-brain-barrier, and the effects of the hemostatic material.

Although interpretation of artifacts versus biological events in the borderline of resection cavity and brain needs further investigation intraoperative MRI seems to be very helpful especially in low grade glioma, where it could increase the rate of complete resection from about half to four fifth. Despite the open question whether the long-term patient-outcome is improved by a more radical resection, intraoperative imaging gives a chance for more radical resections with less complications.

Acknowledgments
We would like to thank D. Becher for her excellent technical assistance. We are grateful to continuous cooperation with A. Oppelt, R. Kuth, T. Vetter (Siemens Medical Engineering, Erlangen, Germany).