Section: **Intraoperative Bildgebung**

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Abstract-Title:
INNOVATION AND LIMITATION OF INTRAOPERATIVE 3D-ULTRASOUND IN NEUROSURGERY – EXPERIENCE IN 44 PATIENTS

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Abstract-Text:
Purpose
Navigated 3D-ultrasound (3D-IUS) is an innovative intraoperative method for real time imaging. Since the first results were published in 1998 it has become under best condition a real alternative for intraoperative MRI and it's less expensive. The common benefits are an intraoperative orientation in 3D, the detection and measurement of brain shift, the visualisation of vessels in space and the use for resection control.
Otherwise only few centres in Norway and Germany are familiar with the possibilities of 3D-IUS in neurosurgery. There is a lack of information about usability, stability and accuracy of the system. There are advantages in clinical routine and intraoperative visualisation for all neurosurgeons as well as pitfalls and limitations during the surgical process. Aim of the paper is the presentation of our experiences in 44 patients under surgical and histopathological principles. Standards and physical parameters are shown using iterative techniques. Our goal is a higher understanding and acceptance for 3D-IUS to establish a 3D-ultrasound platform.

Method
1. Technical System
For navigation support a freehand 3D ultrasound workstation was used consisting of a standard personal computer containing a video grabber card in combination with an optical tracking system (NDI Polaris) and a high end ultrasound device (Siemens G 60 S) with a standard phased array ultrasound probe (Fig. 1). Frequency varied from 7, 5 MHZ in superficial tumours and 6, 0 MHZ in deep-seated lesions.

2. Pre - and postoperative Imaging
Preoperative 3D-MRI data were acquired with an 1, 5 Tesla magnet unit (Symphony, Siemens, Erlangen, Germany) and transferred to the navigation workstation (Localite Navigator). A total of 250 T1w 3D-MR images with a thickness of 1 mm with contrast agent (1 mmol/kg body weight “Omniscan”, GE Medical Systems”) were obtained in each case (FOV: 25 cm, matrix: 256x256, TR: 11.4 msec) for data processing. The area of contrast enhancement (including central necrotic tissue) was defined as tumour and determined as volume in the summary of each slice. For tumors without contrast enhancement an

additional T2w 3D-MR image was obtained and matched with T1w 3D image for better visualisation of tumor margin. In cases with tumor localisation near the circuit of Willis an TOF-MRA (time of flight mRA) was implemented in the 3D-MRI navigation to estimate blood circulation. Registration was performed with skin fiducials.
All patients were undergone an early postoperative MRI including contrast agent within 24 hours after surgery. The data acquisition was carried out in T2w and T1w 2D spin echo technique within only few minutes. In accordance to the preoperative procedure for contrast enhanced tumors the postoperative imaging was performed in T1w with and without contrast agent and subtraction technique to identify tumour remnants. Evaluation of complete and incomplete tumor removal were given independently by neuroradiologist and neurosurgeon.

3. Intraoperative 3D-ultrasound

The ultrasound probe was tracked with an active tracker and worked directly in different depth (6-12cm). B-Mode 3D-ultrasound datasets were acquired after craniotomy (transdural), at different subsequent times of the resection procedure until the end of the operation. The tracked microscope was used as a pointer to define tumor remnants in different scans and to find fixed targets of tumor tissue.
3D-Power Doppler datasets were obtained transdural, after dural incision and at the end of the operation as well. We used the directional mode. Main Doppler parameters (Power, PRF – Pulse repetition frequency and Persistence) were adapted on operative situation.

4. Entrance of the study

Up to June 2006 44 patients were included in the study. Selection criteria were achieved on the basis of size and location of the cranial tumor or vascular malformation. All patients were informed regarding the methodology and agreed the study. The ethics commission voted for our operative protocol. In a standard protocol the expenditure of time for 3D-IUS, the accuracy, usability of the technique and method were documented. Tumor volumes and remnants were analysed comparing pre- and postoperative MR images in relation to intraoperative 3D-iUS. Brainshift was measured as highest deviation for anatomical structures between preoperative MR images and 3D-iUS datasets. Visualisation of tumor adjacent vessels and parts of circle of Willis were described. Neurosurgeons revealed the highest benefit of 3D-IUS after the surgical operation and problems during the operation procedure. Physical ultrasound parameters were analysed for each kind of lesion.

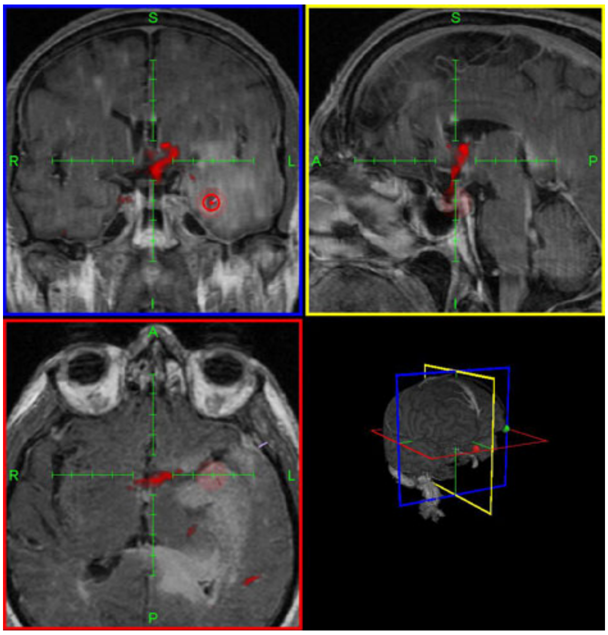
Results

The intraoperative 3D-IUS navigation system was successful without stability problems in all 44 cases. The accuracy of the US-navigator is generally 0.8mm, the FFE was at least 1,3 mm. The expenditure of time for one 3D-IUS datasets is with 2-5 minutes fast enough for intraoperative condition. Maximum brain shift was detected in all cases in a range form 1 to 12 mm (median 4.5) depending on location and kind of tumor. Histopathology findings are shown at table 1. No patient suffered from permanent neurology impairment. Eleven Neurosurgeon evaluate the system qualitatively. No serious lost of quality of the 3D ultrasound images at the end of the operation was measured using the optimal patient position in relation of the transducer to the patient. The phased array transducer offers different frequencies from 6- 7,5 MHZ in relation to the localisation of the tumor. Inexperienced neurosurgeons have the choice to collect up to 10000 2D-US-scans from different angles and directions for one 3D-IUS dataset to avoid individual impact and side

effects.
In gliomas the hyperechoic zone could be detected and removed with 3D-IUS using iterative navigated technique (Fig. 2). All patients with biopsies of washy borders between tumour, oedema and brain tissue showed the transition of normal to pathological tissue. In the remaining malignant gliomas (WHO III-IV) in 17/20 patients (85%) a tumor removal under ultrasound control was possible. In two patients with recurrent glioblastoma the visualisation on the tumor/brain margin was incomplete and in one patient suffering from oligoastrocytoma (WHO III) only the central hyperechoic zone could visualised for resection and orientation. Except one in all patients both the last 3D-IUS and the postoperative MRI demonstrated the same resection result of tumor remnants (95%). Operative strategy was changed to more radical resection after 3D-IUS in seven patients (35%).
In low grade glioma the tumor border was not clearly delineated, but in the two cases with astrocytoma (WHO II) the surrounding oedema was slightly hyperechoic (Fig. 3).
3D visualisation of tumor border is well established in metastasis and meningeomas.
Ultrasound resection control for lymphoma depends directly on the grade of vascularisation and needs additionally the matched preoperative MRI.
In vascular malformation and hemangioblastoma 3D rendering of the vessels with Power Doppler allows additional information about feeders and draining vessels for resection control and operative approach.

Conclusion
The introduction of 3D-ultrasound has increased the value of neuronavigation substantially, making it possible to update ultrasound scans online during surgery and minimize the problem of brain shift. Intraoperative orientation, 3D rendering of vessels, planning of the surgical approach and tumor resection control are main potentials of the 3D-IUS system with improved image quality. Our concept of an ultrasound based navigation equipment including new techniques with available hardware and software under less expensive acquisition is satisfy for the daily routine and further developments in 3D ultrasound visualisation. Phantoms and learning programs could be helpful to make sure neurosurgeons with this intraoperative 3D technique.

Bild 1/JPG



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