ORIGINAL ARTICLE

Image Guided Neurosurgery by Using Neuronavigation Integrated with Intraoperative Three-Dimensional Ultrasound

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ABSTRACT
Introduction: Intra-operative ultrasound provides low cost real time imaging that is simple and rapid to use. In recent years there has been a significant improvement in the quality of ultrasound imaging. Ultrasound integrated neuronavigation can be used to optimize the approach, and achieving safe maximal resection, thereby improving outcomes for patients with different localization and histology of brain tumors, vascular patology, spontaneous intra-cerebral hemorrhage. **Material and Methods:** Since 2007 till 2010, in the Institute of Neurology and Neurosurgery, 130 operations with application of 2D iUS have been performed. Starting from March till May 2012, 17 patients went under surgical treatment using the intraoperative ultrasound integrated neuronavigation system. **Results:** We applied ultrasound neuronavigation system in 17 cases on patients with diverse pathologies, including brain tumors (craniopharyngeoma, corpus callosum and intracerebral glioblastoma, intraaxial glioma), vascular patology (arteriovenous malformations, aneurysms), spontaneous intracerebral hemorrhage. Application of ultrasound neuronavigation system aids in improving postoperative outcomes for these patients. **Conclusions:** The integration of 3D US with neuronavigation technology created an efficient and inexpensive tool for intraoperative imaging in neurosurgery. The technology has been applied to optimize surgery of brain tumors, but it has also been found to be useful in other procedures such as operations for aneurysms or arteriovenous malformations. iUS is easy to use and has a rapid learning curve which makes it a useful tool to the neurosurgeons intraoperative armamentarium.

Keywords: Intraoperative ultrasound, 2D US, 3D US, Neuronavigation, Neurosurgery

INTRODUCTION

Reliable intra-operative orientation in neurosurgery is essential. Anatomical topographic landmarks, frame based and frameless neuro-navigation, iUS allow the neurosurgeon to localize the lesion and surrounding structures, to aid in optimizing the approach and achieve safe maximal resection.[1,2] In brain tumor surgery real time imaging has advantages over preoperatively derived images as during the excision structures move and CSF is lost so these will lead to brain shift, which will make navigation based on preoperative images inaccurate.[3,4] Also during surgery new features can develop (hydrocephalus, hemorrhage, etc).[2] Intra-operative ultrasound is comparatively inexpensive, easy to use, and requires little intra-operative equipment or upkeep.

Intra-operative sonography has been used in neurosurgery since the 50s (intially as A-mode US). In the 1960 B-mode ultrasound became available. In the late 80s, computer technology had developed to a stage making possible the use of preoperative image data for specifying the position of a tool in the brain, thereby the concept of neuro-navigation was born.[1] Recent advances in probe technology, image fusion, 3D techniques have provided considerable improvements to image quality.[2]

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Goals

- Optimizing the approach, and achieving safe maximal resection using confident intra-operative orientation.
- Improving outcomes by applying integrated ultrasound neuronavigation for patients with different localization and histology of brain tumors, vascular patology, spontaneous intra-cerebral hemorrhage.[2,5]

MATERIAL AND METHODS

Since 2007 till 2010, in the Institute of Neurology and Neurosurgery, 130 operations with application of 2D iUS have been performed.[5] Starting from March till May 2012, 17 patients went under surgical treatment using the intraoperative ultrasound integrated neuronavigation system (Figures 1-4).

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Principles of 2D and 3D iUS image acquision

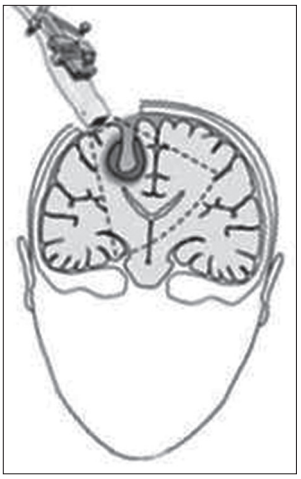

Figure 1: The patient should be positioned properly to obtain a vertical access to the lesion, in order to fill the operation cavity with water.[6]

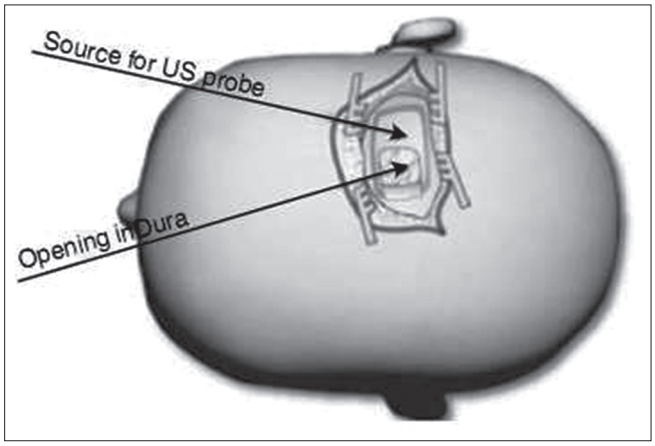

Figure 2: Images are taken at an angle, and aside from the operation access therefore reducing artifacts.[6]

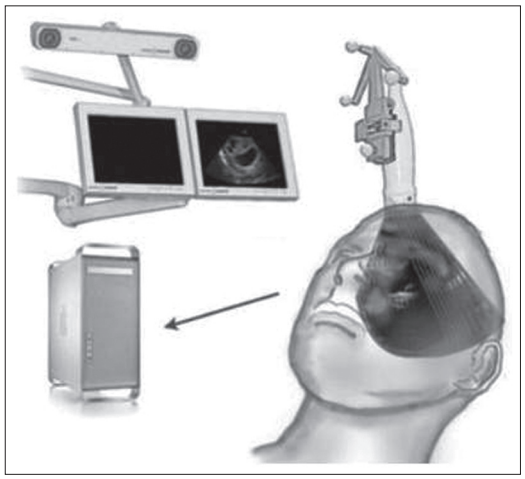

Figure 3: 3D US image acquisition is done during the operation every time is needed. The probe is moved over the region of interest, while each of the 100–200 images is tagged with position data from the optical tracking camera and reconstructed into a regular 3D volume. It takes about 30 seconds to create a new 3D US volume.[1]

RESULTS AND DISCUSSION

Accuracy of 3D Ultrasound

In case of standard neuronavigation system the overall clinical inaccuracy consists of: registration inaccuracy (often more than 5 mm), technical inaccuracy (navigation system itself), and inaccuracy due to brain-shift. For US integrated neuro-navigation, the registration inaccuracy is eliminated because both US acquisition and navigation based on 3D images is done in the same reference system. The inaccuracy due to brain-shift can be abolished by repeated acquisitions of 3D US during the operation.

Once the craniotomy has been performed, iUS can be used to localize the lesion and neuroanatomical structures such as the ventricle, falx, choroid plexus, main vessels and to assess the brain shift (responsible factors - gravity, brain swelling, loss of CSF, tumor debulking).

iUS can be used to check if the removal is complete for lesions with clear edges before excision (the majority of all metastases, meningiomas, cavernomas, abscesses, craniopharyngiomas, and some gliomas). (Figures 5-10).

Applications for 3D Ultrasound Based Neuronavigation

- Surgery of brain tumours
  - Planning of surgery
  - Biopsies
  - Operation guiding
  - Resection control
- Skull base surgery
- Endoscopy
- Cavernous haemangiomas
- Intracerebral haematomas
- Aneurysms
- AVMs surgery
- Intra-spinal pathology.

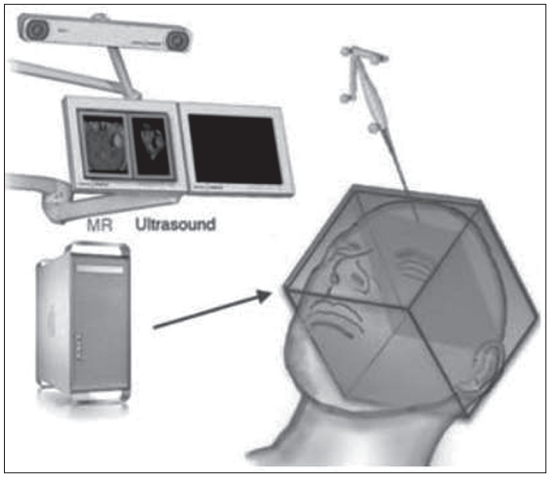

Figure 4: The pointer steers the display of the 3D volume.[1]

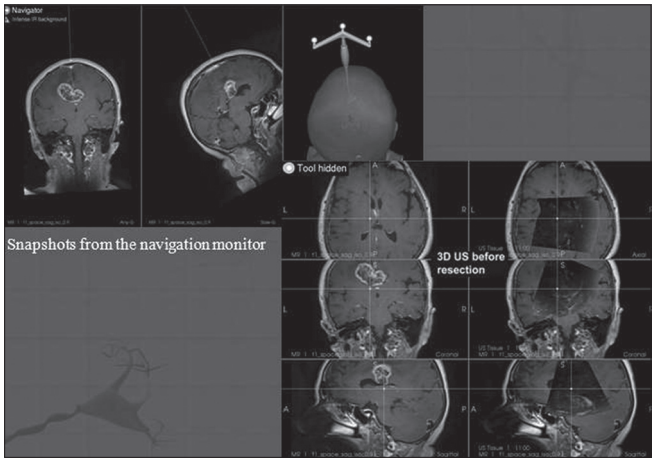

Figure 5: Intraoperative 3D US image acquisition on patient F (female) 39YO (years old) with Corpus Callosum Glioblastoma

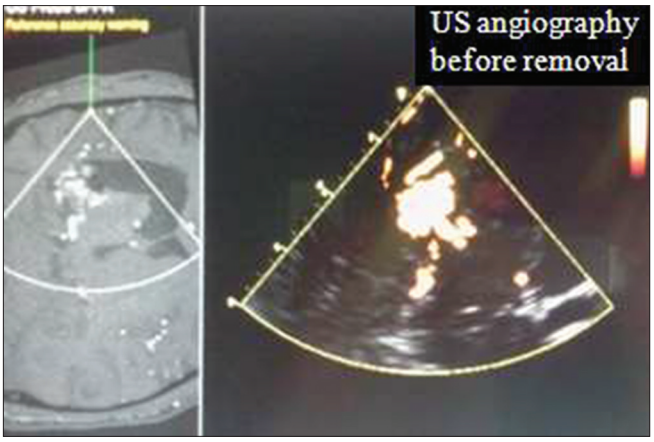

Figure 8: Patient M28YO with Left Temporal AVM, Spetzler-Martin grade IV. We used US angiography – based on recordings of the power Doppler signals from the blood stream

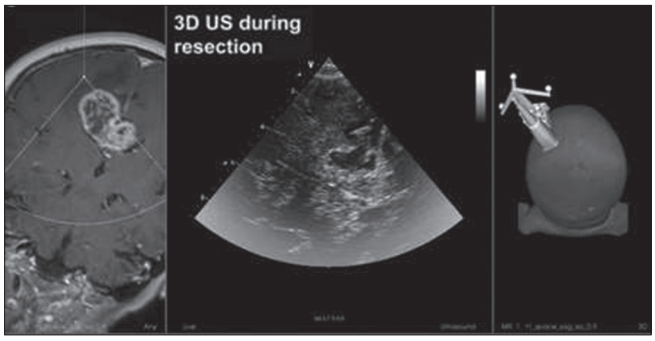

Figure 6: The same patient. Resection guidance using intraoperative 2D US

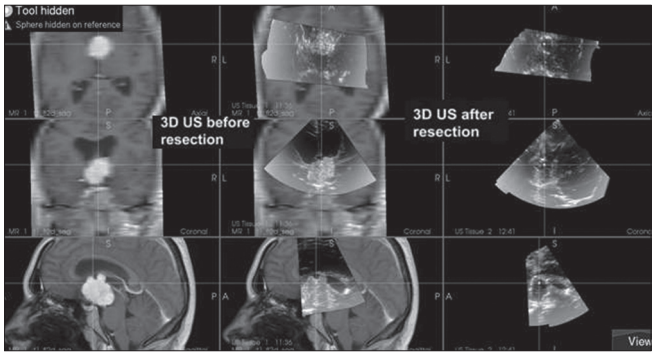

Figure 7: Patient M (male) 29YO with Intra-ventricular Craniopharyngeoma

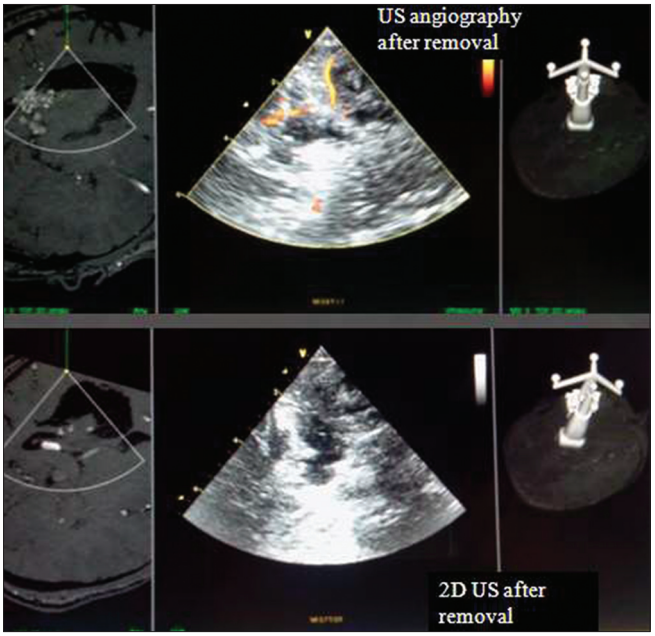

Figure 9: The same patient. Image acquisition (2US angiography - up and conventional 2D US - down) after AVM removal

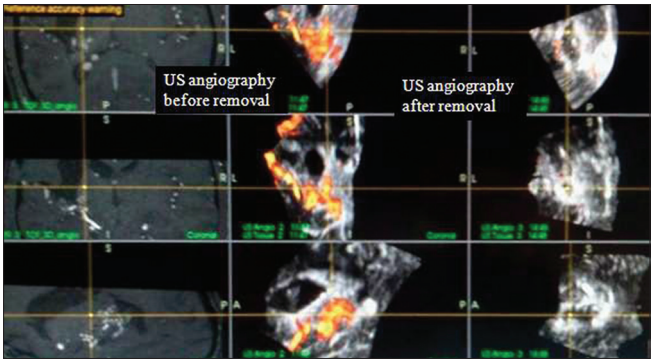

Figure 10: The same patient. Image acquisition (3D US angiography) – before and after AVM removal

Our experience. 3D Ultrasound Based Neuro-navigation was Applied in

- Neurooncology (tumor localization, resection control)
  - Corpus callosum and intracerebral glioblastoma
  - Intraventricular craniopharyngeoma
  - Occipital astrocytoma
  - Recurrent vestibular schwannoma
  - *vascular* (localization and identification of vascular lesions)
  - AVM Spetzler-Martin grade IV

- ACom aneurysm
- *spontaneous intracerebral hemorrhages*

CONCLUSIONS

Ultrasound integrated neuro-navigation is useful in intra-operative imaging of most brain tumors, in addition it enables to work safer, faster and always with more confidence in removing intra-axial tumors especially in eloquent areas and without producing any permanent neurological deficit. Also iUS can be utilized in resection guidance, and gaining the possibility to perform a total tumor removal. Using intra-operative color Doppler (US angiography) provides information about vascular structures, aneurysms and deep-seated AVMs localization, blood flow and vasospasm, allows real time evidence of vessel patency or flow disruption following anevrysm clipping or AVM removal. In AVMs, also was found to be useful in identifying feeders and draining vessels and for resection control.[7] our experience showed that ultrasound integrated neuro-navigation is efficient in optimizing the surgical procedure and the patient outcome. iUS is a low cost intra-operative imaging modality, that with current technological improvements can be as informative as low-field iMRI. iUS is easy to use and has a rapid learning curve which makes it a useful tool to the neurosurgeons intra-operative armamentarium.

Abrreviations

ACom - anterior communicating artery
AVM - arteriovenous malformation
CSF - cerebrospinal fluid
iUS - intraoperatove ultrasound

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