INTEGRATION OF PRE- AND INTRAOPERATIVE MULTIMODAL DATA SOURCES IN NEUROSURGICAL OPERATIONS

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Abstract: Neurosurgical interventions have to be planned accurately and carefully to avoid damage of important functional areas of the brain. Different sources of information like MR images, functional data (e.g. fMRI, EEG, MEG) and atlas data are commonly needed for the planning procedure depending on the specific situation of the pathological process.

We describe a computer-based system which supports the multimodal planning and performing of neurosurgical interventions. The surgical planning process comprises segmentation of relevant anatomical data, definition of appropriate trajectories and labelling of critical sections and security distances. This planning procedure can be performed by an experienced neurosurgeon in less than 15 minutes

Intraoperatively, our system may be linked to a navigation system to indicate the exact position to the surgeon according to the preoperative planning data. Adaptive 3D views which visualize the necessary information for the present surgical situation are provided. Intraoperative imaging and matching techniques compensating the brain shift effect can be applied to allow an exact execution of the planned procedure.

The system can intraoperatively be used to store important landmarks and surgical paths. It additionally supports electrocorticographical recordings.

Introduction

The planning of neurosurgical interventions is a complex process comprising several tasks that basically differ dependent on the type and location of the pathological process. Different sources of information like MR or CT images, functional data [2] (e.g. fMRI, EEG, MEG) and atlas data [3] may be relevant for a specific case. These multimodal data have to be registered before being used for planning purposes. The segmentation of needed anatomical structures like tumours, skull or cortex etc., is also important. Depending on the anatomical structure and the image quality the segmentation may be performed automatically or has to be carried out interactively.

In order to find maximally sparing trajectories to brain lesions the surgeon needs as much information as possible on the surrounding tissue, the neuro-anatomical situation, functional representations and properties, blood supply etc. These information have to be visualized selectively corresponding to the different tasks before and during the intervention. Manipulation of planning data like rotation, zooming and panning is important for the neurosurgeon to understand complex surgical situations.

Intraoperatively, the surgical intervention has to be monitored to detect discrepancies in relation to the planned proceeding. Therefore, the exact position of the neurosurgeon's instrument should be indicated in the preoperative planning data. Intraoperative imaging (like MRI or ultrasound) can be utilized to compensate for the brain shift effect using matching techniques.

In specific cases (e.g. epilepsy surgery or tumours adjacent to eloquent areas) electrocorticographical recordings are used intraoperatively to delimit pathological processes [4]. This procedure can be supported by tracking the related electrode grid. Thus the grid's position and the corresponding electrical activity may be reproduced at any time.

Planning and navigation systems which are commercially available usually support only some parts of the required information sources and procedures. Therefore, we developed an integrated system for planning and performing neurosurgical interventions that supports various scenarios occurring in the operation theatre.

Materials and Methods

Our system uses standard MRI volume data sets in DICOM format modelling the patient's brain anatomy for surgical purposes.

For non-standardized functional data (EEG, MEG and fMRI) flexible internal representations are defined which allow an easy development of new import filters. The import comprises data conversion to the format of the planning system and an appropriate coordinate transformation and matching process. At the moment, the functional analysis software packages Brain Voyager (Brain Innovation, Maastricht, The Netherlands) and BESA (MEGIS Software, Munich, Germany) are supported.

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If required elastically matched atlas structures from a digital brain atlas system [3] can be attached.

Anatomical data can be identified and segmented using a toolbox containing different algorithms like histogram based methods, region growing, watershed and morphological operators. Dependent on the segmentation approach, objects are triangulated or visualized as voxel-based volumes. Some standard objects like the head's surface can be segmented automatically. More complex structures like e.g. the cortex are segmented by the user who interactively controls semi-automatic segmentation tools.

The results of the planning process can be exported to a commercial navigation system using DICOM or vendor dependent formats (e.g. Stryker Corporation). Interesting structures like EEG, MEG, fMRI and atlas objects are thereby considered. This option is easy to use and no additional effort during surgery is necessary (see Fig. 1).

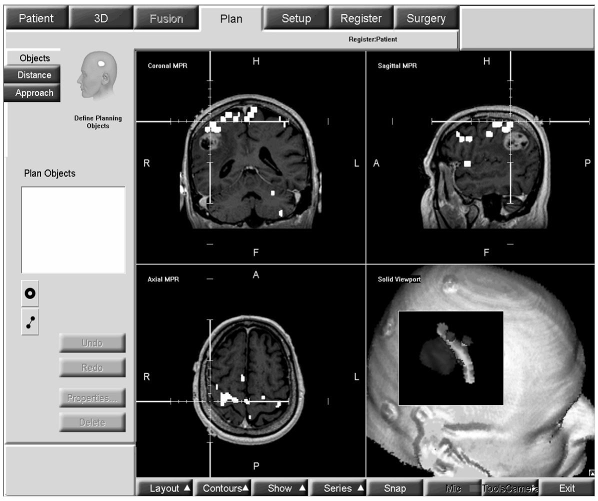


Figure 1: Export of fMRI activations (white dots) to an SNN navigation system. The information was used to segment the precentral gyrus.

Alternatively, the system may be directly linked to a commercial navigation system. Thereby, our system can be used intraoperatively for navigational purposes offering all described features. This option is preferable but also the effort for mounting an additional system in the operation theatre has to been taken into account. Figure 2 shows the work flow of the whole system and the data flows involved.

A registration procedure of our system has to be performed prior to the intervention [1]. Therefore, markers are tracked that were preoperatively attached on the head's surface. These markers have also to be identified in the 3D modelled MRI volume. By this procedure the two coordinate systems of the planning data and the actual patient data have to be matched. As this registration procedure is also needed to initialize the commercial navigation system not much additional effort is necessary to setup our system.

After the registration process the position of the tracked pointer can be visualized on the screen of our planning system including all additional information sources.

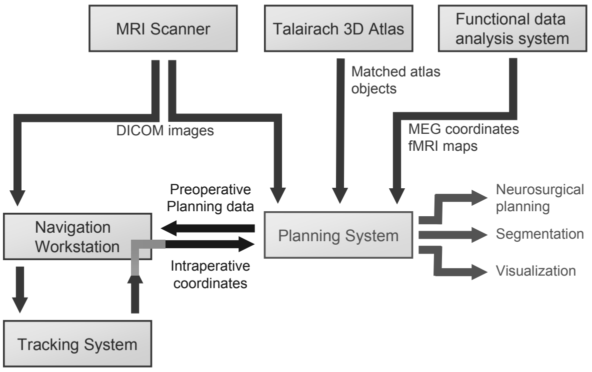


Figure 2: Schema oft the system's workflow. Data may be imported from MRI scanners, the Talairach 3D Atlas or functional data analysis systems. The planning system can be linked intraoperatively to a navigation workstation which makes use of a tracking system.

If necessary the preoperative planning data can be matched onto intraoperative MR images. This may reduce inaccuracies caused by brainshift and therefore increase the overall accuracy of the system. So far, rigid matching approaches are applied because of severe time constraints during the intervention.

Intraoperatively, electrocorticographical recordings are supported by tracking selected electrodes and interpolating the whole electrode grid. As a trade-off between accuracy and tracking speed we favour a combination of linear and parabolic interpolation [4]. Using this approach 6 electrodes have to be tracked to digitize a 4x8 grid being used regularly in clinical routine. Thus, it is possible to remove the electrode grid while continuing with the intervention without loosing the exact location of the electrodes and the functional activations.

The system is programmed in C++ running on a standard Windows PC with one Gigabyte of memory and a fast graphics adapter. The visualization component is based on Open GL and provides a fast visualization with interactive frame rates.

Results

The described system offers a variety of useful processing features for different purposes. Important anatomical structures or lesions can be segmented by different automatic or interactive working procedures. For example the cortex can be segmented from the MRI data stack in less than three minutes (see Fig. 3). In nearly all cases the obtained quality is satisfying for planning purposes.

The visualization component of our system comprises many different options. MRI data is selectively displayed in 2D or 3D views. Multi screen modes may be used to show a large 3D view on one screen and a split view containing axial, sagittal and coronal cross-sections on another one (see Fig. 4). The multimodal data can be displayed selectively as 3D objects or as contour lines on the MR slices (see Fig. 3). Slices can be shifted and positioned independently from each other. The total volume can be arbitrarily rotated. Furthermore, the so-called surgeon's view displays the brain in a cross-section which is oriented perpendicular to the optical axis of the microscope and therefore corresponds to the perspective the surgeon usually has upon the surgical field (see Fig. 4).

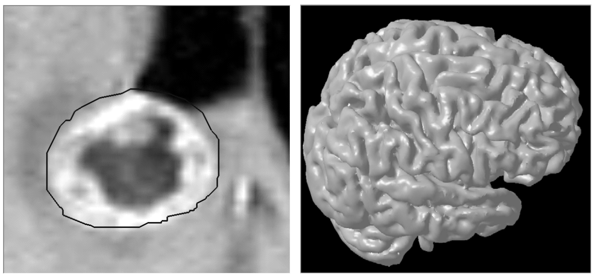


Figure 3: Left: In-plane tumour contour on axial MRI. Right: 3D visualization of the cortex.

The MEG dipoles can be displayed at their corresponding position by spheres with an arrow indicating the direction of the magnetic field. Different sources are labeled with different colors (see Fig. 5).

For the fMRI data, the surgeon can choose between 3D activity clusters and 2D activation maps overlaid onto the MRI cross-sections and the surgeon's view (see Fig. 6). The statistical thresholds and the clustering of the scatter plots can be arbitrarily adjusted via the user interface.

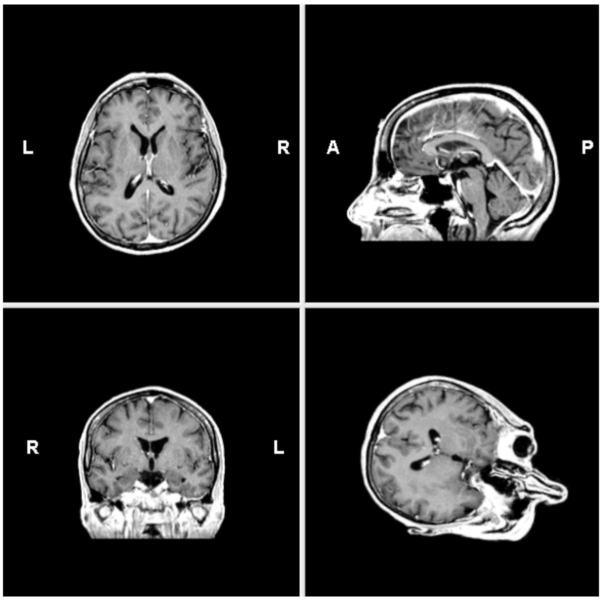


Figure 4: Adjustable split view, from upper left to lower right: Axial, sagittal, coronal cross-section, surgeon's view.

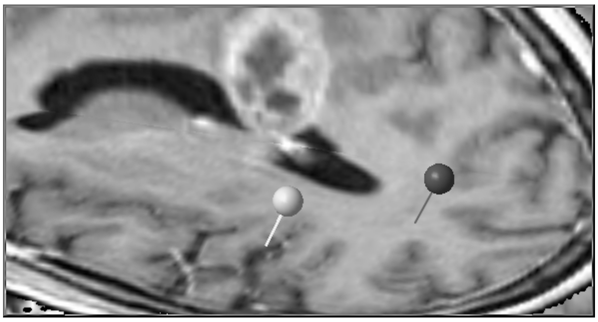


Figure 5: Two MEG dipoles overlaid onto the MRI.

A measurement tool allows for the precise quantification of distances between any desired points in the 3D volume by simply clicking with the mouse cursor. This feature is useful for a variety of different purposes, for example estimating tumour size and extension in different directions, or measurement of distances between vessels and the planned surgical trajectory. It is also possible to quantify the volume of segmented objects.

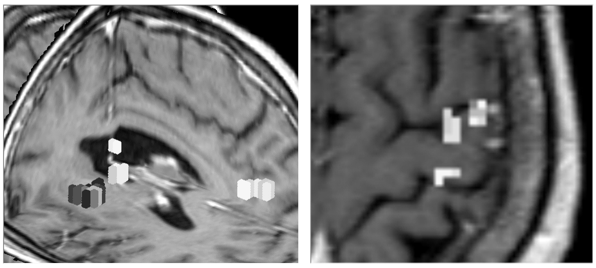


Figure 6: Left: 3D activity clusters of motor activations. Right: 2D activation maps of motor activations.

An additional source of neuroanatomical information is a digital brain atlas system according to Talairach and Tournoux which is developed from our group [3]. This software elastically matchs brain structures of the atlas onto the actual patient's MRI dataset considering pathological processes like tumours. Our system imports the individualized atlas objects and displays them in 3D or as contour overlay (see Fig. 7). Brain structures which have low contrast such as deep gray nuclei or several fibre tracts may be better identified by this means.

In less than 15 minutes the total MRI data set is segmented, visualized, arranged with functional data and additionally matched with atlas information, if necessary. These planning data can then be exported to the neuronavigation system for mapping it onto the patient data model. Alternatively, the planning system may be linked directly with the navigation system.

Intraoperatively, single landmarks and polygons can be tracked using the navigational link.

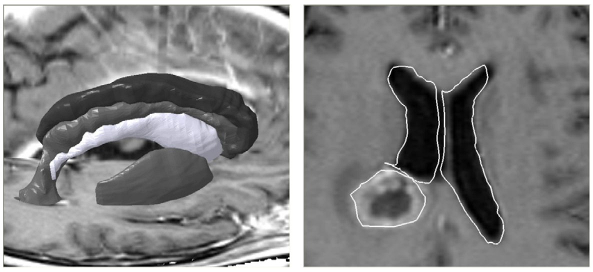
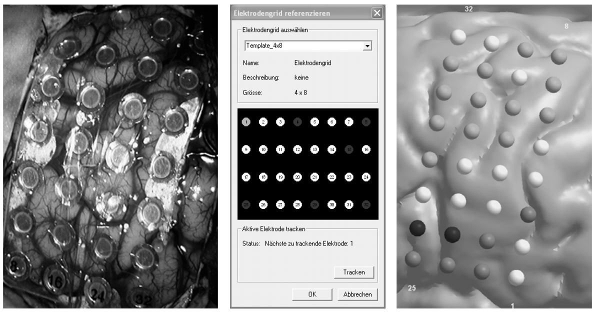


Figure 7: Left: Selected matched atlas structures, in top-down order: corpus callosum, ventriculus lateralis, nucleus caudatus, putamen. Right: Result of elastical atlas matching of the ventriculus lateralis considering the tumour.

If electrocorticographical recordings are to be used the tracking of an electrode grid is easy and quick to perform, e.g. a 4x8 electrode grid can be tracked in less then 1 minute [4]. Firstly, the used grid type has to be chosen. A software wizard indicates the tracking order and shows the user which electrodes have to be tracked (see Fig. 8). After the process is completed the error is displayed to illustrate the tracking quality. The system enables the user to assign different colour codes to the electrodes according to the electrical activity. The grid may be visualised on the cortex at any time during or after the intervention.



Template_4x8
Name: Elektrodengrid
Beschreibung: keine
Grösse: 4 x 8
Status: Nächste zu trackende Elektrode: 1

Figure 8: Left: Photograph of an electrocorticographical recording. Middle: Wizard for tracking electrode grids. Right: Visualization of a tracked electrode grid on a brain phantom with colour coding of electrical activity.

Discussion

The described system is particularly useful for complex neurosurgical planning procedures. The planning process is quick to perform and is accepted by the neurosurgeons. Furthermore, the two different possibilities for intraoperatively reusing the planning data are reasonable dependent on the type of intervention. If only few additional information is required for an intervention it is suitable to export the according data and to use it within the commercial navigation system. This can be accomplished in about 10 minutes using our system. We have applied the system in this way for about 20 cases in clinical routine. No additional manpower is needed as the neurosurgeon uses the navigation system as usual.

Nevertheless, in complex cases (e.g. with the inclusion of different functional information or anatomical atlas data) it usually is preferable to directly use the various information sources and visualization methods of our system available during surgery. The effort is higher because a technician is needed for setup and handling of the system. This feature of the system is currently being evaluated at the Department of Neurosurgery of the University Hospital Heidelberg.

For interventions including electrophysiological procedures the presented grid tracking approach offers a good trade-off between accuracy and tracking effort. The approach is less time consuming and more precise than the ordinary procedure of marking the electrode's positions on the brain's surface. Additionally our approach offers the possibility to use the visualization for documentation purposes and follow-up studies.

Conclusions

Our system is used in the Neurosurgical Department of the University Hospital Heidelberg with good approval by the surgeons. The effort that is necessary to use such a system in the operating theatre has to be reduced if it is to be applied within clinical routine. Therefore a better interoperability with the navigation system is necessary to reduce communication problems and errors. Another important point is to improve the workflow of our system in order to reduce the amount of required user interactions.

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