Image Fusion for Skull Base Neuronavigation

—Technical Note—

Ulrich SURE, Ludwig BENES, Thomas RIEGEL, Dirk Michael SCHULTE,
and Helmut BERTALANFFY

Department of Neurosurgery, Philipps-University Marburg, Marburg, Germany

Abstract

An automatic image fusion module (BrainLab, Munich, Germany) is used for the fusion of the magnetic resonance (MR) imaging and computed tomography (CT) data sets. The procedure of image fusion takes 5 minutes prior to surgery. The image fusion of CT and MR imaging data visualizes the skull base and tumor margins clearly. Color display of the different data sets allows the tumor and the skull base to be distinguished easily. The fused CT data in bone window mode provides useful additional information on the osseous skull base.

Key words: skull base, image fusion, neuronavigation, image guidance

Introduction

Image guidance during skull base surgery has become a routine procedure in many neurosurgical and ear-nose-throat centers, and has many advantages, particularly for surgery of large and complex tumors.¹⁻⁹⁾ We previously discussed the use of image fusion of computed tomography (CT) and magnetic resonance (MR) imaging for neuronavigation in skull base surgery to provide useful anatomical information during the dissection of large tumors.⁸⁾ Such data preparation allows simulation and planning of the appropriate neurosurgical approach for complex tumors.⁸⁾ Here, we describe recent technical developments in the image guidance fusion software and illustrate the advanced intraoperative display modalities that are provided by a modern neuronavigation system.

Neuronavigation System

The VectorVision 2 (BrainLab, Munich, Germany) navigation system consists of a trolley-mounted array incorporating two infrared cameras, a mobile computer workstation with high-resolution monitor (and touchscreen technology), and handheld pointers. Infrared light-emitting diodes are positioned around the cameras. The instruments are equipped with easily attachable reflective markers, also called

passive markers, that reflect the infrared light to the cameras for position calculation. This allows armless and wireless tracking of the pointers and surgical instruments. The software contains tools for virtual pointer elongation, path planning, and caliper measurement.

Adhesive skin fiducial markers are applied widely over the skull vault, with a cluster over the region of interest, before CT or MR imaging is performed. The data sets are transferred via an intranet in DICOM format to the workstation, and the position of each fiducial marker is selected either manually or automatically. The tumor imaging data are outlined, stored, and can be reconstructed in any plane. The patient-to-image registration is performed using a nonsterile pointer with the patient positioned and fixed in a standard head clamp.

After registration, the axial, coronal, and sagittal reconstructions of the pointer tip position are displayed in real-time on the monitor. The registration accuracy is calculated by the software, but the application accuracy can be checked by visual inspection for system validation. During surgery the monitor is draped and can be handled by the surgeon using the touchscreen technology.

Image Fusion

The image fusion function is used to correlate the anatomic information from two complementary image sets. In principle, the image fusion technique

Fig. 1 **A:** Intraoperative composite navigation screenshot during surgery for a large pontine and temporo-mesial pilocytic astrocytoma that was removed by a combined pterional and subtemporal transtentorial and transpetrous approach. The screenshot shows the direct fusion of the computed tomography (CT) (light yellow) and the magnetic resonance (MR) imaging data (light blue) in the axial (upper right) and coronal images (lower center), the axial (lower left) and sagittal MR images (lower right), the bone window CT image (middle left), and the intraoperative microscopic view (upper left). The pointer is directed at the petrous bone during petrous drilling as shown in the microscopic view (black arrow) and the CT and MR imaging planes. **B:** Preoperative axial MR image (upper) showing the temporo-mesial and brainstem infiltration of the tumor and the postoperative MR image with the tumor removed (lower).

works with data for any patient. The main use is to obtain additional information for the standard CT planning data set. For example, a MR image clearly depicting a skull base tumor can be matched with a CT scan with poor enhancement of the tumor. The superior accuracy of the CT scan can thus be used for registration of the patient whereas the clearer MR image is used for intraoperative navigation with better contrast enhancement. At least one CT image set is necessary for image fusion to provide the undistorted and artifact-free information. Although it is possible to match two image sets manually, it is usually quicker to use the automatic image fusion module at first to provide an optimized starting point for any further manual adjustments. The automatic image fusion software can process different

modalities (CT, MR imaging, positron emission tomography, etc.), regardless of the scan direction of the respective image sets. The image sets may be truncated provided that the region of overlap is sufficient. The software is not dependent upon particular imaging parameters such as CT and MR imaging slice ranges or specific slice thickness. A slight discrepancy in the matched sets can be identified and compensated using the anatomical structures as a reference.

The automatic image fusion software computes a rigid transformation from one image set into the other such that the image sets match. Distortions of the MR images are noncritical, since they occur mainly in the boundary regions of the images and the automatic image fusion is based on the undistort-

Fig. 2 A: Intraoperative composite navigation screenshot during surgery for a large meningioma of the anterior skull base which had widely infiltrated the anterior and middle fossae as well as the orbita, and was removed through a combined orbito-zygomatic and temporal approach. The screenshot shows the magnetic resonance (MR) image (upper left) and the direct fusion of the computed tomography (CT) and MR imaging data (upper right). The CT scan shows the osseous skull base in a light yellow color (white arrows) which is fused to the axial MR image with contrast enhancement. The screenshot shows the unfused CT image (middle left) and the bone window CT image (lower left), and the three-dimensional image of the osseous skull (lower center) in a view similar to that after positioning during surgery. The screenshot also includes the coronal MR image with contrast enhancement (lower right). The pointer (yellow arrows) is directed at the tumor-infiltrated lateral orbital wall during tumor dissection and removal. B: Preoperative axial MR images showing the tumor infiltration of anterior skull base including the orbita and both the temporal and frontal lobes.

ed center regions. The algorithm is insensitive to artifacts or objects visible in only one image set (localizers, etc.). A click of the AutoFuse button in the software starts the automatic image fusion module. Successful image fusion can be achieved in most cases without manual pre-registration of the image sets. If the result is not satisfactory, the user may use the translate and rotate functions to provide a rough initial registration as the initial state for the algorithm.

Image fusion algorithm: The search space consists of all rigid transformations of one image set with respect to the other. Each rigid transformation is described by the amount of translation and rotation. The task of the automatic image fusion module is to find the unique transformation in the search space that brings the image sets into registration. The automatic image fusion module uses a similarity parameter to evaluate the quality of a particular translation and rotation. This parameter is valid for

any statistical relationship of the image intensities. The same tissue type may have different intensities in the image sets. The similarity parameter is calculated by investigating the intensity values of a large number of image points and comparing them to the counterpart points in the other image set. The determination of the matching transformation is formulated as an optimization problem: Find a set of transformation parameters such that the similarity parameter reaches a maximum. The algorithm runs in several steps. Each step uses finer image details for the calculation of the similarity parameter than the previous one. The first step uses a few image data points, which makes the optimization fast and robust. The next iterative steps improve the match, taking into account more and more image information. An optimization algorithm is used to find the maximal value of the similarity parameter and the related transformation parameters. As evaluation of the similarity parameter is very time consuming, a search strategy has been implemented that uses as few evaluations as possible.

Completion of the image fusion: After completion of the image fusion, some misalignment of the sets may still occur due to image distortion, poor definition of the anatomical landmarks, or actual physical differences between the landmarks, because tumor growth or surgical/radiotherapy treatment may have distorted the shape of the ventricles. Therefore, further fine adjustment can be carried out manually to improve the fusion quality.

Both image sets are then used for target volume definition and treatment planning. Structures outlined in the first image set can now be displayed in the second image set, and vice versa (Fig. 1). The image fusion function may also be repeated with any other available image set (Fig. 2). Before starting surgery, anatomical reference structures common to both data sets are used to verify the accuracy of the fusion.

Acknowledgment

The authors acknowledge the perfect technical support by Jens Witte (BrainLab, Munich, Germany).

References

- 1) Bertalanffy H, Sure U: Surgical approaches to the jugular foramen, in Robertson JT, Coakham HB, Robertson JH (eds): *Cranial Base Surgery*. London, Edinburgh, New York, Churchill Livingstone, 2000, pp 237–258
- 2) Dorward NL, Alberti O, Velani B, Gerritsen FA, Harkness WFJ, Kitchen ND, Thomas DGT: Postimaging brain distortion: magnitude, correlates, and impact on neuronavigation. *J Neurosurg* 88: 656–662, 1998
- 3) Gumprecht HK, Widenka DC, Lumenta CB: BrainLab Vectorvision neuronavigation system: technology and clinical experience in 131 cases. *Neurosurgery* 44: 97–105, 1999
- 4) Hayashi N, Kurimoto M, Hirashima Y, Ikeda H, Shibata T, Tomita T, Endo S: Efficacy of navigation in skull base surgery using composite computer graphics of magnetic resonance and computed tomography images. *Neurol Med Chir (Tokyo)* 41: 335–339, 2001
- 5) Hill DLG, Hawkes DJ, Crossman JE, Gleeson MJ, Cox TCS, Braceley EEC, Strong AJ, Graves P: Registration of MR and CT images for skull base surgery using point-like anatomical features. *Br J Radiol* 64: 1030–1035, 1991
- 6) Mann WJ, Ecker U: Application of navigation systems in skull base surgery. *Otolaryngol Pol* 54: 273–276, 2000
- 7) Mehdorn HM, Schrader B, Nabavi A, Hempelmann R: [Neuronavigation in the region of the skull base]. *Laryngorhinootologie* 79: 404–411, 2000 (Ger, with Eng abstract)
- 8) Sure U, Alberti O, Petermeyer M, Becker R, Bertalanffy H: Advanced image guided skull base surgery. *Surg Neurol* 53: 563–572, 2000
- 9) Sure U, Hellwig D, Bertalanffy H: Incorrect vector after calibration of surgical instruments for image guidance: the problem and the solution: technical note. *Minim Invasive Neurosurg* 44: 88–91, 2001

Address reprint requests to: U. Sure, M.D., Neurochirurgische Klinik der Philipps-Universität Marburg, Baldingerstraße, D-35033 Marburg, Germany.
e-mail: sure@post.med.uni-marburg.de.

Commentary on this paper appears on the next page.

Commentary

Neurosurgeons are guided by preoperative imagings, surgical observation and hand feeling during surgery. MR images with Gd offer information on soft tissue structures, and additional bone target CT image on bone structures. The image fusion technique could be useful to demonstrate the overall impression in the neurosurgeon's brain. However, it must be noted that T_2 -weighted MR imaging contains almost all information without image fusion, such as the difference of bone quality. One disadvantage of T_2 -weighted imaging might be the low resolution between cancellous bone and air. Bone target CT has been useful during opening the mastoid air cells or paranasal sinuses, and the fusion technique could be beneficial in this area. This technique will be useful for fusion of structural and functional images, such as functional MR imaging, positron CT, Xe-CT or MEG, in the near future. The future task may be how to reproduce the fusion image in a short time, without management by the neurosurgeon.

Takeshi KAWASE, M.D.
Department of Neurosurgery
School of Medicine
Keio University
Tokyo, Japan

In this article, Sure and co-workers have described very accurately, the technical use of an automatic image fusion module. The VectorVision 2 navigation system (BrainLab, Munich, Germany) has allowed

rapid and precise fusion of MR imaging and CT data sets, the procedure of image fusion have taken merely 5 minutes before surgery. The BrainLab system could be effectively used with a mobile computer workstation and a high resolution touchscreen monitor, offering easy use in daily routine. The superior accuracy of the CT scan could be applied for registration of the patient whereas the MR image was used for intraoperative orientation. The fused CT data provided useful additional information on the osseous structures removing skull base tumors, as demonstrated in Fig. 2. Unfortunately, as a pure technical description, this surgical experience could not be demonstrated with large clinical series, treating different intracranial lesions. In addition, the fusion of CT and MR data did not solve the most important principle drawback of the so called "navigation" systems, namely the lack of intraoperative, real time information. Based on preoperative radiological diagnosis, this system could not solve the problem of detection of brain shifting and intraoperative changing of the pathoanatomical situation, which is one of the major obstacle in precise orientation. In this sense, only the application of precise intraoperative real time imaging, with intraoperative mobile CT, MR, or 3D ultrasound, can be the basis of real intraoperative navigation.

Axel PERNECZKY, M.D.
and Robert REISCH, M.D.
The Neurosurgical Department of Medical School
University of Mainz
Mainz, Germany