

Use of Preoperative and Intraoperative Magnetic Resonance Tractography in Intracranial Tumor Surgery

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The goals of every modern neurosurgeon during surgery for intracranial tumors can be summarized as follows: 1) a small and less invasive craniotomy; 2) a resection as wide as possible; 3) the preservation of eloquent areas and white matter major tracts (WMMTs); and 4) the minimization of postoperative morbidity.

The development of image-guided neurosurgery improved the microsurgical treatment of brain tumors, of vascular malformations, and of other intracranial lesions. The dynamic changes of intracranial contents regularly occurring during the surgical procedures (the so-called brain shift) sometimes invalidates the preoperative surgical planning and, therefore, only intraoperatively acquired images allow us to perform what is the closest to real intraoperative image-guided neurosurgery presently available.

Magnetic resonance imaging (MRI) currently represents the more elegant imaging method for intraoperative image guidance, mainly because of excellent imaging qualities and avoidance of ionizing radiations.^{5,9–11} The development and clinical application of intraoperative MRI passed through 1) low to very low field systems; 2) midfield systems; and 3) high-field systems.

The major advantages of high-field intraoperative MRI are: 1) acquisition of high-quality images; 2) functional capabilities (magnetic resonance spectroscopy, functional MRI, magnetic resonance angiography, chemical shift imaging, diffusion-weighted images, and more); and 3) updates of data outside the magnet at any time by using neuronavigation systems.^{5,9–12} The latest concept of intraoperative high-field MRI has been developed by a cooperation of Siemens and BrainLab companies and is the so-called BrainSuite.

BrainSuite (*Fig. 21.1*) is an operative theater with 1.5-T MRI (Siemens, Erlangen, Germany) integrated with a neuronavigation system, a microscope tracked with navigation software, and digitized image transfer (BrainLab, New York, NY). In this room, the patient is placed on a rotating operating table. During surgery, the head and the operative area are

placed outside the 5 Gauss line. For this reason, surgical procedures can be performed with standard neurosurgical instruments and microscope.

At any time during the operation, the surgical procedure can be interrupted and the patient can be placed into the magnet by simple rotation of the table.

The BrainSuite was installed for the first time in Europe in the Department of Neurosurgery of the University of Roma “La Sapienza”–Sant’Andrea Hospital during 2004.

The advantages of high-field intraoperative MRI and the BrainSuite concept can be summarized as follows: 1) high-quality images, including angio-magnetic resonance sequences; 2) use of standard surgical instruments; 3) integration with a neuronavigational system and possibility of image update at any moment; and 4) functional images: a) spectroscopy, b) diffusion and diffusion tensor imaging (DTI), and c) fiber tracking.

Diffusion Tensor Imaging: Diffusion Tensor Imaging–Magnetic Resonance Imaging

The diffusion MRI sequences analyze the Brownian movements of water molecules in cerebral tissues. In the gray matter, the movements of molecules of water are free, whereas in the white matter, the movements of molecules of water are in accordance with the direction of fibers (the so-called anisotropic movement). In areas of cerebral ischemia, the severe cytotoxic edema reduces the movement of molecules of water in both the gray and white matter.^{1–4,6–8,13}

Fiber tracking algorithms 1) compare local tensor field orientations measured by DTI from voxel to voxel; and 2) allow delineation of white matter major tracts. With this technology, it is possible to obtain colored three-dimensional reconstruction of WMMT with graphic resolution of relationships between tracts and gray matter.⁸

Therefore, DTI-based fiber tracking allows visualization, deformation, displacement, and infiltration of WMMT caused by space-occupying lesions. The knowledge of positioning of WMMT in relation to intracranial tumors (*Figs. 21.2–5*) may help to optimize surgical resection and to prevent new neurological deficits.^{1–4,6–8,12,13}



FIGURE 21.1. Main components of the BrainSuite.

In a series of 37 patients operated on for intracerebral glioma, Nimsky et al.⁵ were the first in reporting that the comparison of preoperative and intraoperative fiber tracking images visualizes a marked shifting and deformation of WMMT because of tumor removal. Shifting justifies the need for an intraoperative update of navigation systems during resection of deep-seated tumor portions near eloquent brain areas or WMMT. Therefore, they concluded that preoperative visualization and intraoperative confirmation of WMMT allows safe resection of gliomas near eloquent brain areas.⁴ In a series of 238 patients, Wu et al.¹² recently concluded that DTI-based functional neuronavigation contributes to maximal safe resection of cerebral gliomas with pyramidal tract involvement, decreasing postoperative motor deficits for both high- and low-grade gliomas, improving the quality of survival for patients with high-grade glioma.

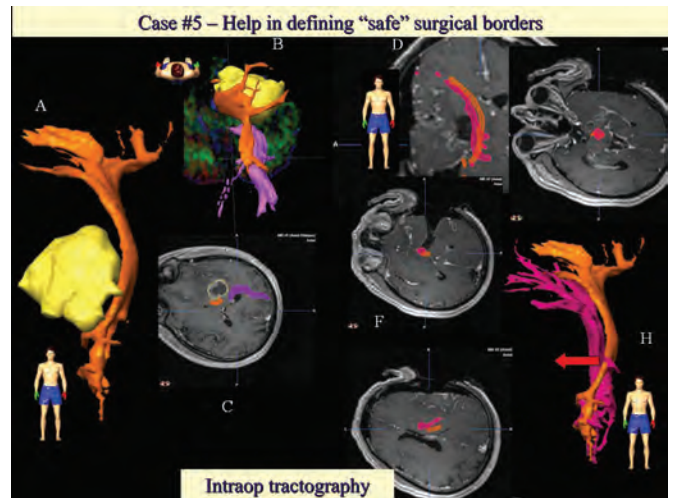


FIGURE 21.3. Case #5: the preoperative and intraoperative tractography helped the surgeon in defining the "safe" surgical borders of resection.

In relation to these considerations, the major aim of our study was to investigate the use of preoperative and intraoperative magnetic resonance tractography during intracranial tumor surgery, evaluating the intraoperative displacement of major white matter tracts during resection in comparison to preoperative DTI-based fiber tracking.

MATERIALS AND METHODS

General Data

From September 1, 2004, to September 1, 2007, we operated on 723 consecutive patients with elective cranial pathologies in our BrainSuite. Since October 2006, DTI-

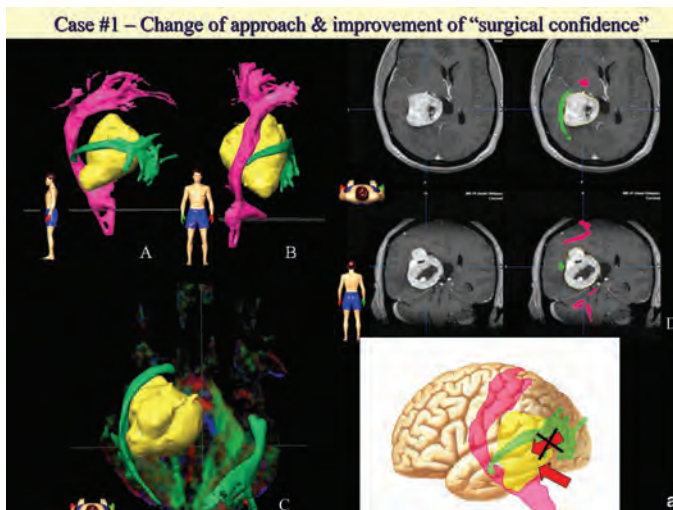
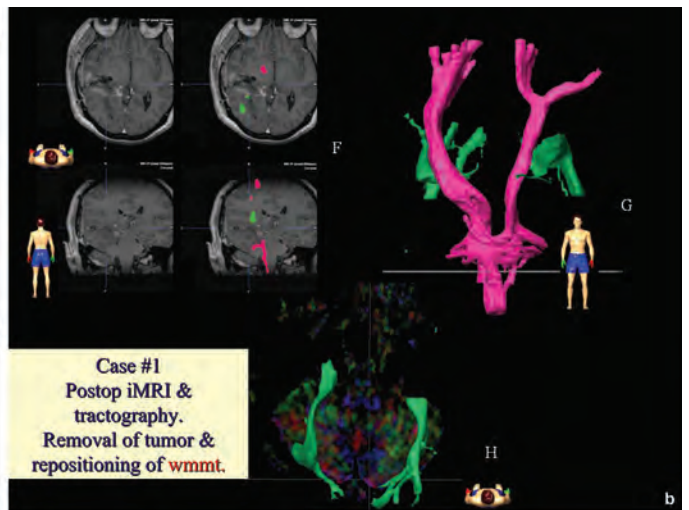


FIGURE 21.2. Case #1: the preoperative and intraoperative tractography allowed selection of the best approach and improved the "surgical confidence" of the surgeon operating on the brain.



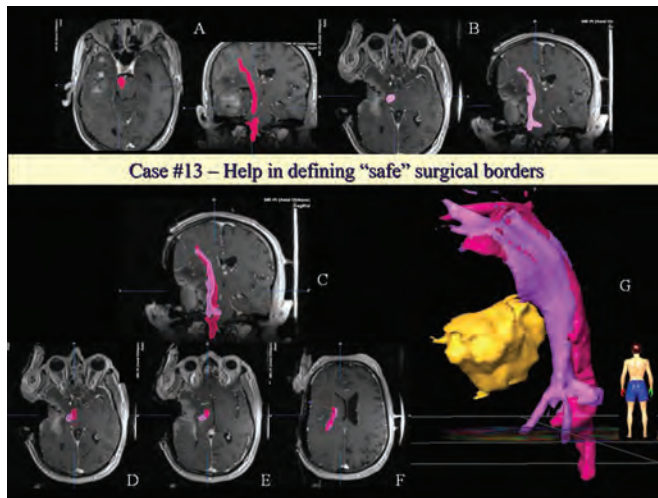


FIGURE 21.4. Case #13: intraoperative iMRI with tractography contributes to define the “safe” surgical borders of tumor removal.

based fiber tracking was generated before, during, and after intracranial tumor surgery by the neuroradiologists after the orientation of WMMT.

Starting Point and Aims of the Present Study

The starting point of the present study is to visualize the shifting of WMMT with DTI-based fiber tracking during intracranial tumor surgery by using our high-field intraoperative magnetic resonance system. Fiber tract visualization is generated in a few minutes and is routinely performed before,

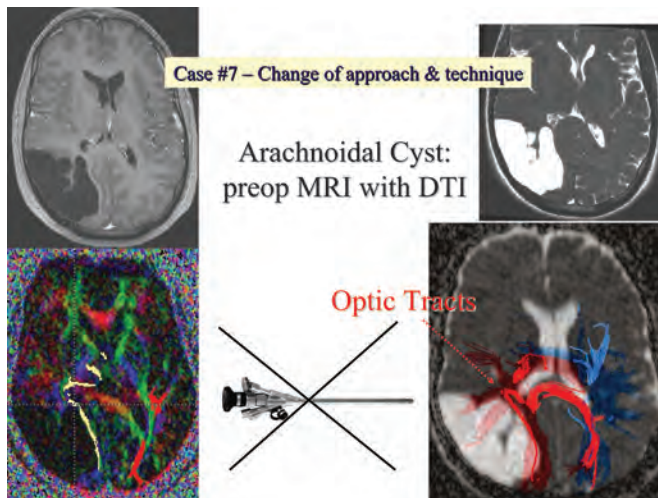


FIGURE 21.5. Case #7: a young man with headache caused by right parietal-occipital arachnoidal cyst. Preoperative iMRI with tractography prompted us to change surgical technique and approach, avoiding damage of optic tract. Marsupialization of the cyst was performed by standard craniotomy; the optic tract remained intact on postoperative DTI-MRI.

during, and after surgery in all patients with an intracranial tumor. Electrophysiological validation at the time of surgery was possible only for pyramidal tracts, whereas we could not validate visual and speech pathways during surgery.

The aims of the study are the following: 1) preoperative evaluation of anatomical relationships between WMMT and tumor; 2) impact of these informations on surgical planning; 3) preoperative, intraoperative, and postoperative evaluation of integrity and positioning of WMMT; and 4) preoperative and postoperative neurological examination of patients to evaluate clinical evidence that WMMTs were not injured.

Clinical Materials and Methods

Forty consecutive patients operated on for a supratentorial space-occupying lesion either involving or adjacent to one or more WMMTs (pyramidal tract, optic radiation, arcuate tract) were analyzed. In 23 cases, the lesion involved the sensorimotor area, in 11 one of the areas of language, and in six the temporal-occipital area. *Table 1* classifies the cases according to histology. In all cases, images of fiber tract position were obtained before surgery, during the operation (with a newly acquired MRI), and at the end of each procedure.

In relation to preoperative and intraoperative data, we tried to answer to the following three questions: 1) Did preoperative and intraoperative magnetic resonance tractography modify the surgical approach? 2) Was preoperative and intraoperative magnetic resonance tractography helpful in defining the borders of resection in relation to WMMT position? 3) What was the impact of preoperative and intraoperative magnetic resonance tractography on the “surgical confidence” of neurosurgeon with the brain? (retraction, coagulation, and so on).

RESULTS

Table 21.2 summarizes the cases operated on until September 2007 classified by pathology. Fiber tracking was performed in the last year during intracranial tumor surgery.

As a whole, the answers to the three questions were the following:

TABLE 21.1. Histological classification of space-occupying lesions of current series

Intracranial Lesion	No. of Cases
High-grade gliomas	17
Astrocytomas—low-grade gliomas	10
Meningiomas	7
Cavernous angiomas	2
Gangliocytomas	2
Non-Hodgkins lymphoma	1
Arachnoidal cyst	1

TABLE 21.2. Classification by pathologies of patients operated in the BrainSuite of the Sant'Andrea Hospital of Roma (Italy) during the first 3 years of activity

Pathology	Percentage of Cases
Intracerebral tumors	41%
Meningiomas	28%
Pituitary adenomas	14%
Aneurysms, arteriovenous malformations, cavernous angiomas	9%
Other (craniopharyngiomas, epidermoids, cysts, acoustic neuromas, microvascular decompression, and so on)	8%

Question 1

In 45% of cases, the answer of the four neurosurgeons was “yes”; that is, in 18 cases, preoperative and intraoperative magnetic resonance tractography induced the surgeons to change the surgical approach selected at the first evaluation (see *Figs. 21.2* and *21.5*).

Question 2

In 50% of cases, the answer of neurosurgeons was “yes”; that is, in 20 cases, magnetic resonance tractography was helpful in defining the borders of resection of tumor in relation to the position of WMMT (see *Figs. 21.3* and *21.4*).

Question 3

In 50% of cases, the answer of neurosurgeons was “yes”; that is, in 20 cases, magnetic resonance tractography had a favorable impact on the procedures, enhancing the “surgical confidence” of surgeons with the brain, allowing the retraction, the coagulation, and the other manipulations necessary for tumor excision in a safer way.

On the clinical side, a partial damage of WMMT on postoperative neurological examination was observed in three cases: two parietal–occipital glioblastomas (hemianopsia in both cases) and one low-grade left temporal astrocytoma (partial aphasia). In two of these cases, the optic radiation was involved and in one the arcuate tract. In all these patients, an incomplete recovery was observed within 6 months after surgery.

DISCUSSION

The aim of every modern brain surgeon is the maximization of surgical benefit with minimization of surgical risk. One of the main risks is the proximity of tumor to critical areas of the cerebral cortex and of white matter such as the motor, somatosensory, language, and visual functions areas.

In relation to the literature,^{5,9,10,11} our preliminary experience with intraoperative high-field MRI proved to be

effective for the surgical treatment of supratentorial and infratentorial tumors, allowing intraoperative evaluation of the procedure, reducing morbidity, and improving the quality of life of patients.

The possible shifting of WMMT has to be taken into account after major tumor parts are resected. Thus, the knowledge of tract position during surgery helps to prevent postoperative neurological deficits. Functional MRI allows surgeons the ability to localize critical cortical areas and WMMT and can thereby reduce the risk of their inadvertent injury.

DTI-MRI fiber tractography can provide unique quantitative and qualitative information to aid in visualizing and in studying fiber tract architecture in the brain. In particular, DTI-MRI with a fiber tracking algorithm is a method for preoperative and intraoperative localization of WMMT, allowing delineation of white matter major tracts and showing their position after substantial tumor removal.^{1–4,6–8,13} The validation of DTI data with intraoperative electrical monitoring enhances the affordability for pyramidal tract localization.⁸

In our study, preoperative and intraoperative fiber tracking was used to plan and guide neurosurgical procedures of excision of intracranial tumors in the vicinity of functionally important areas of the brain. In approximately half of cases, the neurosurgeons involved in surgical procedures judged tractography useful in selecting the safer surgical approach, helpful in defining the borders of tumor resection in relation to WMMT and relevant in enhancing the “surgical confidence” of the neurosurgeon with the procedure.

In conclusion, compared with the information provided by conventional MRI, DTI-MRI provides superior quantification and visualization of relationships between an intracranial tumor and WMMT. In particular, preoperative and intraoperative DTI-MRI with fiber tracking (tractography) allows visualization of WMMT, showing their position after removal of parts of intracranial tumor, especially if guidance is needed for further resection. In our preliminary experience, three-dimensional visualization of white matter fibers such as corticospinal (pyramidal) tract, optic radiation, and arcuate fasciculus with relationship to intracranial tumors was extremely helpful for preoperative and intraoperative evaluation of WMMT position, reducing surgical morbidity.

Disclosure

The authors did not receive financial support in conjunction with the generation of this article. The authors have no personal or institutional financial interest in drugs, materials, or devices described in this article.

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