The role of MR tractography in pre-surgical planning – personal series of 25 cases and a review of the literature

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Abstract

Diffusion tensor imaging (DTI) contains a wealth of information on molecular diffusion in biological tissues [1,2]. Visualizing the white-matter tracts using diffusion anisotropy maps represents one of the applications with a major impact on neurosurgical case management [3]. Knowledge of the topography, integrity, and involvement by the pathological process of the white matter tracts is an important factor in pre-surgical planning for patients with brain lesions. We have evaluated the clinical utility of a magnetic resonance tractography technique based on DTI.

We studied, in a prospective manner, 25 cases with lesions involving salient intracerebral and medullary tumors (22 and 3 cases respectively). All cases followed a preoperative imaging protocol that included DTI on top of the usual MR imaging protocol. We analyzed the DTI findings preoperatively and looked at the significant information that influences the surgical plan: position of the significant white matter tracts, the degree of their involvement in the pathological process and anatomical integrity, relationships with important anatomical landmarks and with the major surgical approach paths. We present the postoperative results and some of the most illustrative cases in the series and compare our results with the similar studies in the literature.

Our experience, based on the results of the present study strongly suggests that in depth knowledge of the white matter tracts involvement in an intracerebral or intramedullary pathological process improves significantly the surgical planning in terms of surgical procedure safety and functional outcome.

Introduction

Planning the adequate surgical procedure for removal of a pathological process within the brain or the spinal cord requires a thorough knowledge of the particular relevant anatomy preoperatively. The goal of maximal safe resection is difficult to achieve without detailed information of functional areas and structures and their relationship with the pathology. The advent of diffusion tensor imaging has revolutionized the study of white matter tracts in the living human brain. Tractography has made it possible to study the detailed anatomy of white matter tracts and to depict important information for neurosurgical planning.

Arguably correct pre-operative identification of white matter tracts is at least as important as the identification of eloquent cortices, such as the motor cortex. First, the precentral gyrus (the location of the motor cortex) can usually be identified by the operating neurosurgeon by visual inspection. Second, direct intraoperative white matter stimulation is much less reliable than cortical stimulation. On the other hand, it is essentially impossible to identify separate white matter tracts, such as the cortico-spinal tract (CST - the main motor tract) or the thalomo-cortical tract (the main sensory tract) by visual inspection as they traverse the corona radiata.

In the present study we have investigated the role of MR tractography in pre-surgical planning for pathological processes affecting both the brain and the spinal cord. All patients underwent neurological evaluation, including assessment of motor and language functions preoperatively and at two points postoperatively. The imaging and clinical data was retrospectively analyzed to assess the factors that help predict the postoperative outcome and the contribution of white matter tracts involvement in the pathological process as an outcome prognostic factor. A special emphasis was given to the tailoring of surgical approach when tract information (direction of displacement, relationship with the tumor) is included in the surgical algorithm.

Materials and method

25 patients with expansive processes of functional areas were introduced in the study. The age of patients was between 20 and 66 years (median 48 years). All patients, 14 men and 11 women underwent a magnetic resonance investigation protocol which included standard sections (T1, enhanced T1, T2, Flair, TOF) supplemented with diffusion tensor imaging. Magnetic resonance imaging studies were performed on a 1.5 T scanner standard RM (Siemens Avanto) using a standard rectangular cage. DTI studies were performed as part of a preoperative imaging protocol. Component of an institutional protocol, informed consent was obtained for each patient to participate in the DTI study, prior to investigation.

The color-coded maps obtained from the DTI scan were analyzed. In each case the tumors were confined to just one hemisphere which favored a direct, within subject comparison of the affected white matter tracts in the tumor baring hemisphere with the contralateral, control hemisphere. The white matter tracts were characterized as follows: displaced, if they maintained normal anisotropy relative to corresponding contralateral tract but was located in an abnormal location or abnormal orientation according to the standard color code, edematous, if they maintained normal anisotropy and orientation but showed obvious increase in intensity on T2 images, infiltrated if they were characterized by reduced anisotropy yet remained visible on the orientation maps and degenerated if the anisotropy was significantly reduced as such there was no identifiable tract on the orientation maps. For tracts characterized as infiltrated we did not try to determine whether anisotropy was reduced as a result of vasogenic edema, tumor infiltration or a combination of these factors. Such a distinction is extremely difficult if not impossible only by DT imaging.

Patients with lesions that involved the speech areas underwent awake surgery as a method to monitor the specific neurologic function intraoperatively. These patients received local anesthesia so that the basic functions of motor speech could be evaluated. Patients were not intubated in order to be able to respond coherently to the tests performed during surgery. In the first stage, cortical mapping was performed by identifying tumor and sulci and giri using macroscopic anatomical landmarks and intraoperative ultrasound. The same mapping was repeated before resection, to avoid any damage to the eloquent area. The patient was asked to perform various counting exercises (repeat counting several times from 1 to 10) and the image naming tests. For the naming task, we used the DO 80, which consists of 80 black and white pictures selected according to variables such as frequency, familiarity, age of acquisition and level of education. [13]

Results

For the 25 patients that were included in the present study the location of the pathological process was temporal lobe in two cases, frontal lobe, two cases, insula, five cases and parietal region in three cases. Dominant neurological symptoms on admission, except for headache with or without intracranial hypertension syndrome (present in 18 cases), were motor deficits and motor aphasia (11 and 9 cases respectively), and seizures (9 cases), accompanied by a severe confusional syndrome in 3 cases. Intracranial hypertension was manifested in three patients enrolled in the study (Figure 1).

Pathological examination of the resection specimens documented glioblastoma in twelve cases, grade one astrocytomas in five cases and grade two in one case, meningioma in five cases, mature teratoma and AVM in one case respectively. We managed to identify the degree of involvement of white matter tracts in all cases using DT imaging 2D maps and 3D reconstructions. Normal white matter tracts were highlighted in the controlateral hemisphere in all patients. Changes in tracts structure and position were characterized for each patient. White matter involvement by the expansive replacement space was classified according to criteria: displacement, infiltration, degeneration and edema in relation to contralateral correspondents (Figure 2). Upper longitudinal beam was deflected in the axial direction or lateral median in twelve cases. Corticospinal tract was diverted in fifteen cases. Locating individual displacement was a variation depending on where the tumor lesion. Deviation has been emphasized in the corona radiate (Figure 3).

White matter tract edema was documented in three cases. Reconstruction of DTI showed reduced anisotropy without displacement of white matter architecture, which is suggestive of tumor invasion. Diffusion tensor imaging documented the destruction of white matter tracts in seven cases (Figure 4). Lower anterior longitudinal component of the beam in the temporal lobe was engulfed by glioblastoma. In the second case, another massive temporo-insular glioblastoma produced distruction of antero-posterior oriented fibers and projections, especially cortico-spinal tract and previous thalamic radiation, the more evident when compared with fibers intact controlateral hemisphere. In one case it revealed diffuse swelling along the outer edges of the tumor. In one case with glioblastoma temporal lobe edema on the outskirts of optical radiation involved parietal and temporal regions. Edema affecting optic radiation white tracts was demonstrated on T2 images of conventional MRI.

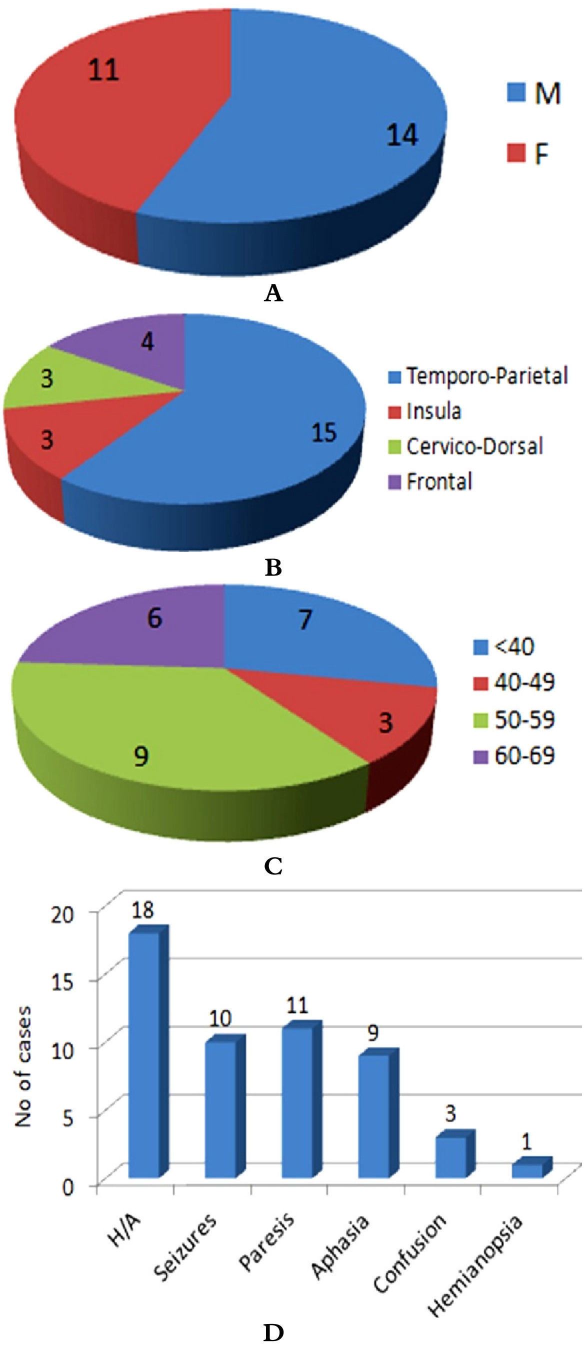


Figure 1 **A** Sex distribution of the cases in our series. **B** Major location of cerebral lesions in all cases. **C** Age distribution; **D** Symptoms at presentation

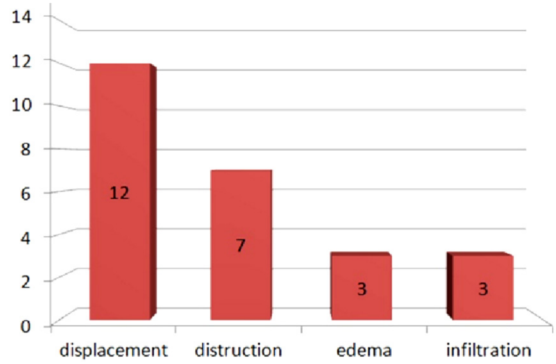
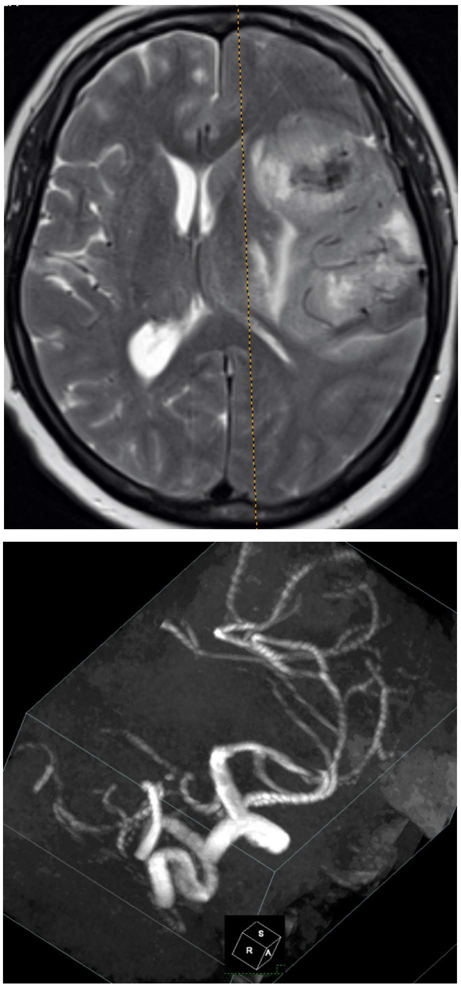


Figure 2 The type of white matter tract involvement by the pathological process



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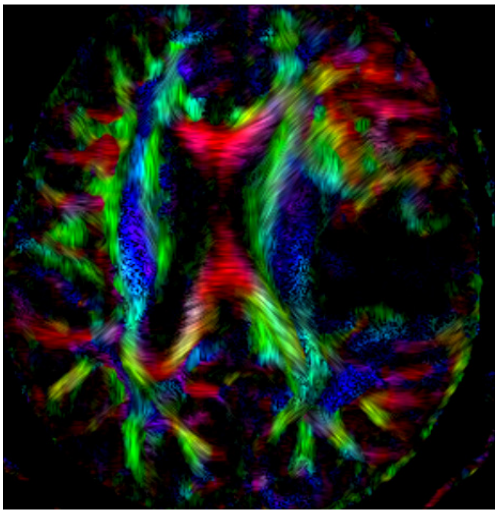

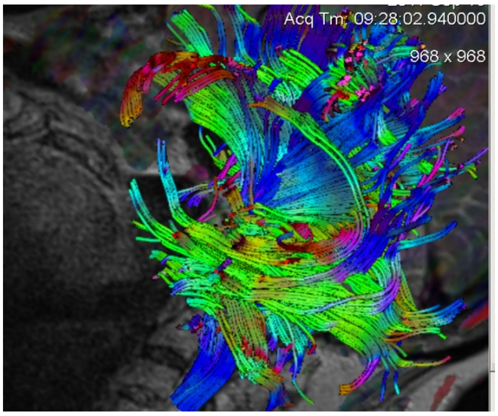

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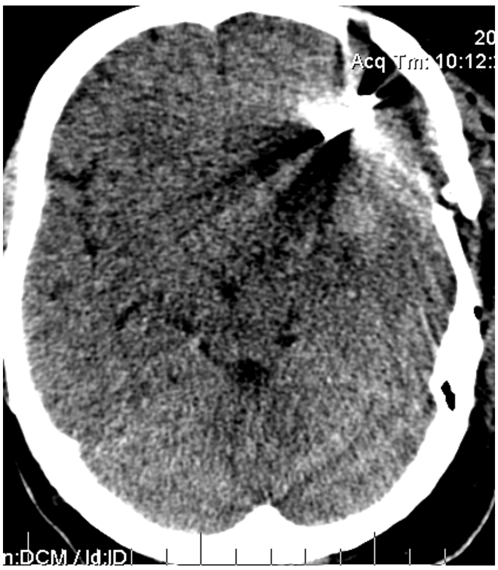
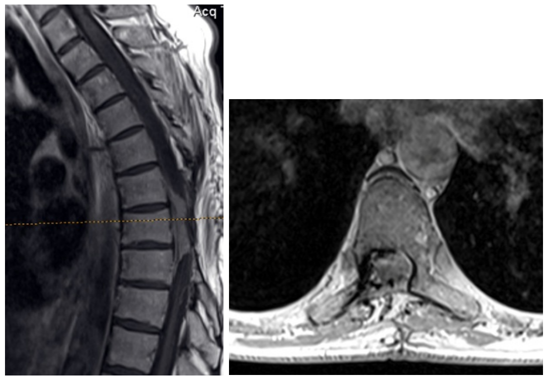


C

Figure 3 Illustrative case for the imagistic work-up in our series. **A** T2-weighted and MRI Angio of the primary lesion. **B** 2D and 3D tractography showing displacement of the longitudinal temporal white matter tracts and compression on the pyramidal tract. **C** Postoperative control CT with the artefacted image of a vascular clip



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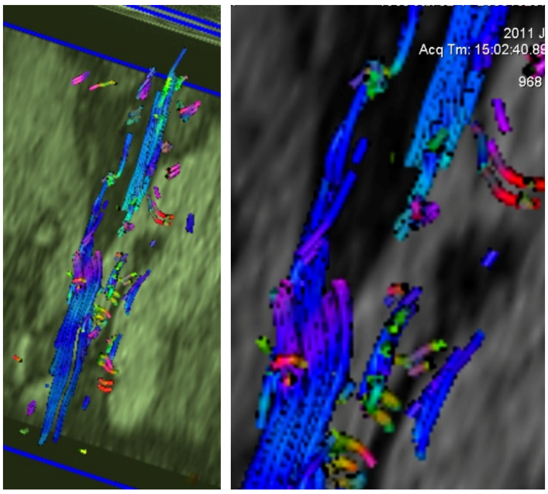

B

Figure 4 Illustrative case for a spinal cord tumor in our series. **A** T1-weighted sagittal (left) and axial (right) MR image showing compression at the level of D6. **B** 3D tractography (whole – left and detail – right) showing almost complete distruction of the descendent white matter tracts in the spinal cord

Using a preoperative planning that takes into account important functional mapping elements directly or indirectly involved in the intracranial expansive process as well as an appropriate selection of cases for intraoperative monitoring of motor and language functions, postoperative results allowed for good postoperative results. Thus, all patients included in this study showed postoperatively similar or improved neurologic status (no iatrogenic neurological deficit). Evaluation of pre- and postoperative Karnofsky performance scale (Karnofsky performance scale - KPS) is detailed in Figure 5.

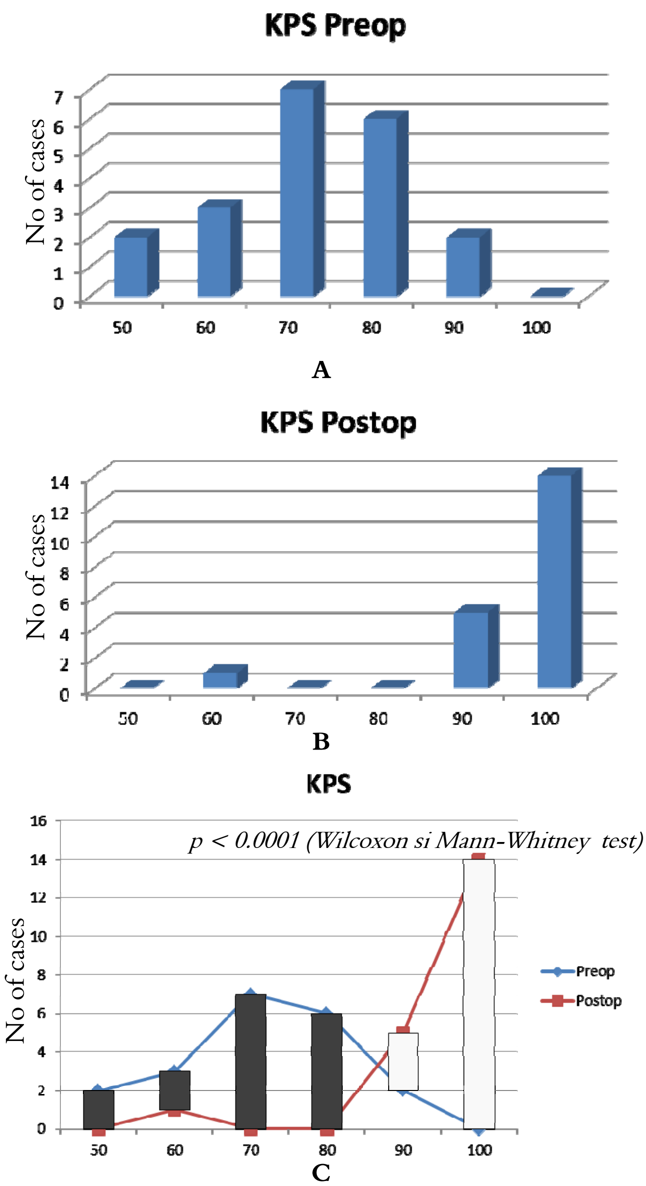

Figure 5 Karnofsky performance scale values pre- and postoperatively (A and B, respectively) and the tendency in the KPS in the whole group. Full bars indicate a negative tendency while the empty bars show positive tendency

Discussion

Brain tumors can affect both functional cortical gray matter and white matter tracts. A good neurological outcome following the resection of intracerebral pathological processes requires a detailed preoperative understanding of their anatomical relationships with functional areas and of adjacent cortical white matter tracts. This is of paramount importance when the tumor develops in or near a functional cortical area in the dominant hemisphere, be it motor, sensory, or cognitive. Understanding the location of the lesion in relation to surrounding functional tissue is a vital element in developing an efficient surgical plan.

The purpose of using various techniques of mapping is to delineate functional areas so they can be preserved during surgery. Maximal tumor resection was shown to be an element closely related to patient survival and improved clinical status of patients on long-term, indicating a main predictor of clinical course. The present data show that tumors that invade massively the functional cortex areas of maintain still intact white matter tracts in the mass of the pathological tissue. Diffusion tensor imaging provides valuable information for identifying tracts when they are displaced by the tumor.

Twenty-five cases were analyzed in our study to demonstrate how diffusion tensor imaging contributes important additional information that may help elucidate the complex relationship between a tumor and surrounding brain tissue. Imaging evidence of the existence of intact white matter tracts in the areas of tumor invasion were obtained in four patients. Other patients showed tracts displacement from their normal anatomy position. In one case with glioblastoma located centrally in the left hemisphere, corticospinal tract lesion in the corona radiata moved medially and superiorly. The information on the displacement of the tracts helped surgical planning by providing information about localization and adaptation of new surgical corridor so as to avoid intraoperative destruction of intact tracts. In this case the tumor was approached from a posterior temporal direction, allowing for aggressive resection of the tumor while avoiding motor fibers previously diverted.

In our study we found that the use of an operator plan which aims at maintaining an intact neurological function is checked by favorable postoperative results. We mention that new neurological deficits occurred in only 12.5% of patients and have largely improved in the first month postoperatively. These results indicate that although they minimize the risk of injury of the functional cortex or tracts adjacent or involved in the pathological process, the methods used do not guarantee the absence of postoperative dysfunction. These deficits were caused probably by touching the subcortical areas, retraction, edema or ischemia. However, based on the results of this study, the risk of harming a previously intact patient during awake craniotomy remains low. This information about the risks of surgery is useful and should be communicated by the surgeon to the patients and their families.

Conclusions

In agreement with the existing prospective studies, our study suggests that preoperative planning based on functional criteria and the use of awake craniotomy offers clear advantages for the resection of intraxial and spinal pathological processes. This allows for intraoperative brain mapping that helps identify (and by consequence, protect) eloquent functional cortex, and is an effective surgery for lesions of different histological types that occur in various locations in the brain. Awake craniotomy to avoid complications of general anesthesia, based on the data of this study and others, is associated with reduced complications and mortality rates and reduced use of resources. As a general principle, we suggest that the awake craniotomy provides an excellent alternative to traditional surgery for supratentorial brain lesions.

The effect of brain tumors on white matter tracts is clearly demonstrated by means of standard diagnostic imaging. Diffusion tensor imaging allowed identification of several viable tracts within a cerebral hemisphere invaded by a tumor. In our series, information provided by DT imaging allowed precise definition of relationships between cortical structures and subcortical white matter and brain tumors. Involvement of white matter tracts is important information in planning the surgical approach in assessing the extent of tumor resection to keep it within safe limits.

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