3D diffuse tensor imaging important acquisition in diagnostic and preoperative planning of intracranial lesions

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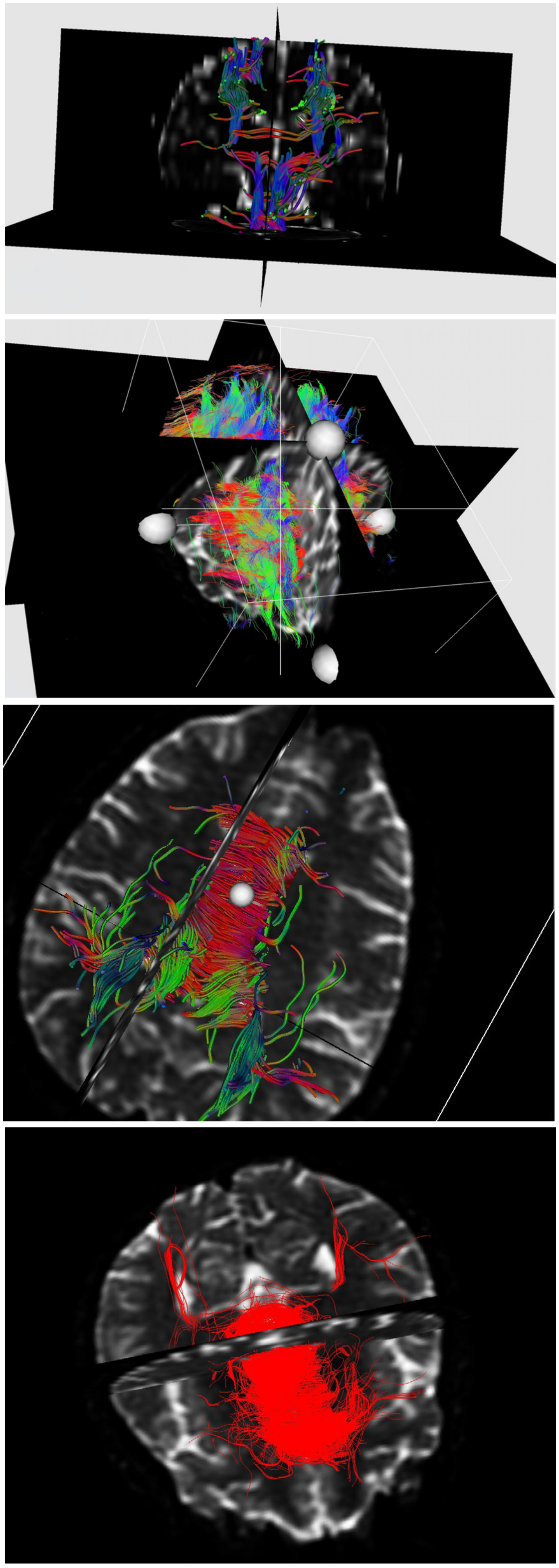
Abstract

Diffusion tensor imaging (DTI) is a MRI technique that enables the measurement of the diffusion of water in tissue in order to produce neural tract images. DTI allows clinicians to look at anisotropic diffusion in white-matter tracts, but it is limited in demonstrating spatial and directional anisotropy. Advanced methods such as color coding and tractography (fiber tracking) have been used to investigate the directionality. The localization of tumors in relation to the white matter tracts (infiltration, deflection), has been one the most important initial applications. Tractography potentially solves a problem for a neurosurgeon in terms of minimizing functional damage and determining the extent of diffuse infiltration of pathologic tissue to minimize residual tumor volume. In this way, tractography facilitates preoperative planning. Tractographic images may help to clarify whether a tumor is compressing, abutting, or infiltrating the contiguous white-matter tracts. DTI identify different tumor components, and to differentiate tumor invasion from normal brain tissue or edema. The recent development of DTI allows for direct examination of the brain microstructure, and DTI has become a useful tool for investigation of brain disorders such as stroke, epilepsy, MS, brain tumors, and demyelinating disorders.

Keywords: diffusion tensor imaging, neurosurgery, tractography.

Introduction

Diffusion tensor imaging (DTI) is a MRI technique that enables the measurement of the diffusion of water in tissue in order to produce neural tract images (Figure 1). The idea of using diffusion data to produce images of neural tracts was first proposed by Aaron Filler & colleagues in March of 1991. Several months later (1992) the first DTI image showing neural tracts curving through the brain was produced. Conventional magnetic resonance (MR) imaging has been the standard clinical tool to characterizing and localizing brain tumors. Topical, MR imaging is used to determine the appropriate therapy and for neurosurgical planning if lesion resection is possible. However, even the most anatomically detailed MR imaging does not allow an assessment of specific white matter (WM) tracts. DTI data can be used to visualize the major WM tracts of the brain [1..3]. DTI is an MR technique that can indirectly evaluate the integrity of WM by measuring water diffusion and its directionality in three dimensions [4]. DTI has been applied to differentiate edema from tumor, in patients with brain tumor for tumor characterization and to assess structural properties of the adjacent tracts [5..10].



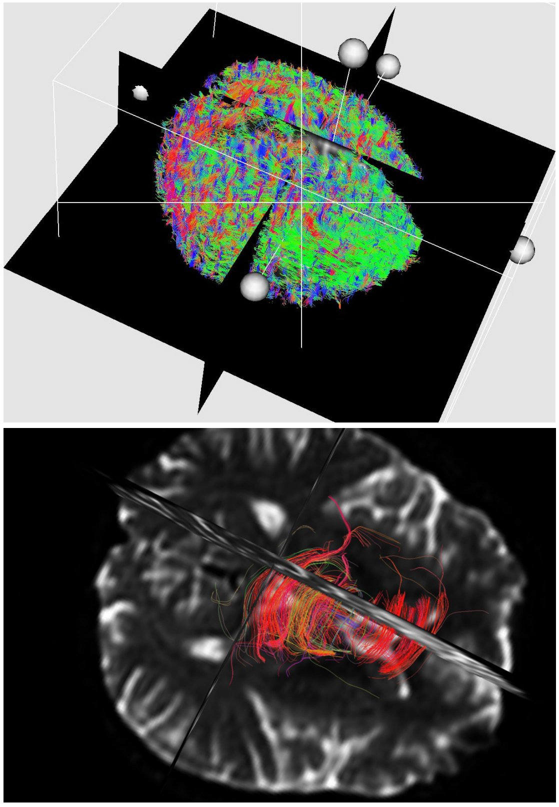


Figure 1 The first images of tractography from our research project

Knowledge of the anatomical relationship between tumor and WM tracts could improve preoperative risk analysis and decrease the risk of WM tract injury during surgery. To minimize injury to the WM tracts adjacent to the tumor, knowledge of their structural integrity would be important.

Experimental

The principal application of DTI is in the imaging of white matter where the location, orientation, and anisotropy of the tracts can be measured. DTI allows clinicians to look at anisotropic diffusion in white-matter tracts, but it is limited in demonstrating spatial and directional anisotropy. Advanced methods such as color coding and tractography (fiber tracking) have been used to investigate the directionality. If diffusion gradients (i.e. magnetic field variations in the MRI magnet) are applied in at least 3 directions (6 directions improves the accuracy) - that describes the 3-dimensional shape of diffusion.

The fiber direction is indicated by the tensor's main eigenvector which can be color-coded, yielding a cartography of the tracts' position and direction: red for left-right, blue for superior-inferior, green for anterior-posterior. No consensus has been reached about an appropriate criterion standard for evaluation the accuracy of DTI, and this technique is primarily investigational at present.

Tractography potentially solves a problem for a neurosurgeon in terms of minimizing functional damage and determining the extent of diffuse infiltration of pathologic tissue to minimize residual tumor volume. In this way, tractography facilitates preoperative planning. Tractographic images may help to clarify whether a tumor is compressing, abutting, or infiltrating the contiguous white-matter tracts. DTI identify different tumor components, and to differentiate tumor invasion from normal brain tissue or edema. DTI has demonstrated a potential in distinguishing gliomas and solitary metastasis in the brain parenchyma. Significantly higher mean diffusivity, compared with levels in normal-appearing white matter, have been demonstrated in the peritumoral regions of both gliomas and metastases. Peritumoral mean diffusivity of metastases and meningioma is significantly higher than that of gliomas. Some clinical applications of DTI are in the tract-specific localization of white matter lesions such as trauma and in defining the severity of diffuse traumatic brain injury.

The localization of tumors in relation to the white matter tracts (infiltration, deflection), has been one the most important initial applications. In surgical planning for some types of brain tumors, surgery is aided by knowing the proximity and relative position of tumor. The use of DTI for the assessment of white matter in development, pathology and degeneration has been the focus of over 2,500 research publications since 2005.

Results and discussions

Tractography combined with functional MRI may potentially help in preoperative planning of brain tumors by mapping areas of active infiltration. The recent development of DTI allows for direct examination of the brain microstructure, and DTI has become a useful tool for investigation of brain disorders such as stroke, epilepsy, MS, brain tumors, and demyelinating disorders.

In the surgery of patients with brain tumors, preservation of vital cerebral function is as important as maximizing tumor resection. The associated morbidity of aggressive resections can be significantly reduced by carefully preservation of vital cerebral function, and the quality of life of these patients will be largely improved. Simultaneously maximizing tumor resection can reduce the chance of recurrence of tumors and improve longer patient survival and long-term functional status [11,12]. For realizing these two goals, many imaging modalities were used to assess brain tumors, which include conventional MRI, positron emission tomography, magnetoencephalography, and functional MRI [13..15]. These tools were used to determine the relationship of tumors with surrounding cortical function areas but provide no information concerning the status of the eloquent white matter tracts. Knowledge of the structural integrity and location of eloquent white matter tracts relevant to cerebral tumors is crucial in neurosurgical planning, because damage to these clinically eloquent pathways can result in postoperatively neurological deficits as damage of functional cortical areas. It is very important for designing appropriate neurosurgical plan that determining the exact location of tumors relevant to eloquent white matter tracts.

DTI is an important progress in the field of MR imaging. It is the only imaging method that can visualize the 3D structures of white matter tracts in the brain in vivo. Recently some researchers have reported that DTI can be used to illustrate the relationship of clinical eloquent white matter tracts with brain tumors [16,17], and they were all restricted to preoperative studies.

In general, cerebral tumor may alter the adjacent WM in three different ways: by (1) displacing the WM tracts but with relative preservation of the fibers, (2) infiltrating the WM tracts, and (3) disrupting of the WM tracts.

Intracranial tumors may involve both functional cortical gray and white matter tracts. Resection of these lesions requires a detailed understanding of functional anatomical relationships to surrounding tissue and adjacent white matter connections. This is most critical in dealing with eloquent cortical regions in the dominant hemisphere in which motor, sensory, speech, and cognitive functions are situated. An understanding of the location of the lesion in relation to surrounding eloquent tissue assists the surgeon in developing an intraoperative plan.

Many diagnostic modalities are currently used to define eloquent regions of the brain. Standard MR imaging, positron emission tomography, magneto-encephalography, and fMR imaging are some of the tools used to investigate the location of functional cortex areas. [18..22] These preoperative studies aid in identifying regions of the brain involved in the cortical activities of sensation, motor, and speech. Preoperative targeting of these areas helps in determining critical relationships of lesion location and surrounding cortical function. The images can then be fused with frameless stereotactic devices, allowing for the planning of optimal surgical approaches and determining the degree and volume of tumor resection. [22] Preoperative diagnostic studies still must be confirmed by intraoperative cortical mapping of functional areas in many cases. Intraoperative cortical mapping has been shown to maximize the extent of tumor resection and to minimize the associated morbidity of aggressive resections. [23]

The goal of using these various mapping techniques is to delineate functional areas so that they can be preserved during surgical resection. Aggressive surgical resection of brain tumors has been shown to correlate with longer patient survival and improved long-term functional status. [24, 25] Some neurosurgeons advocate the removal of cortical tissue appearing grossly abnormal during the operative procedure, that is, based on the premise that areas of functional tissue are either displaced or destroyed by infiltrative tumors. [26]

Researchers of other studies found that tumors that grossly invade areas of functional cortex may still retain functional fiber tracts within the pathological tissue. Using intraoperative cortical stimulation, Ojemann, et al., [27] limited the extent of resection by demonstrating gross invasion of tumor into cortical and subcortical structures.

It is unclear if these fibers are displaced or obliterated by tumors. Diffusion-tensor imaging provides information on the directionality of water molecules at the cellular level, thus indicating the orientation of fiber tracts.

In tissue with an ordered microstructure, like cerebral white matter, orientation can be quantified by measuring its anisotropic diffusion. Diffusion-tensor calculations permit the characterization of diffusion in heterogeneously oriented tissue. [28] The spatial orientation of myelinated fiber tracts can then be represented as distinct white matter maps in easily read, color-coded directional maps. [29] Recently, various investigators have used directional diffusion information to create maps of white matter connectivity. [30..32] These techniques may be valuable for tract identification when the white matter tracts are displaced by tumor.

Diffusion-tensor imaging is a useful new preoperative diagnostic tool for evaluating lesions close to vital cortical and subcortical structures.

Knowledge of this displacement assisted in preoperative planning by informing the surgeon of the tract's shifted location, thus allowing for adaptation of the surgical corridor to avoid destruction of the communicating white matter bundles. In this instance the tumor was approached from a frontal direction, allowing for aggressive resection at the frontal pole of the tumor while avoiding the posteriorly deviated motor fibers. This resulted in postoperative improvement of the patient's hemiparesis, presumably due to the elimination of pressure on the corticospinal tracts.

Conclusions

The recent development of DTI allows direct examination, in vivo, of some aspects of brain microstructure. DTI has already shown to be of value in studies of neuroanatomy, fiber connectivity, and brain development. It has become interesting for investigation of different brain pathology, such as cerebral ischemia, trauma, MS, presumed AD and cognitive impairment, epilepsy, brain tumors and metabolic disorders. However, further improvement in technique and stable postprocessing analyses is needed to increase the utility of DTI in both research and clinical applications.

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