"Two are Better than One": Combining fMRI and DTI Based Fiber Tracking for Effective Pre-Surgical Mapping

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Synopsis

Functional MRI (fMRI) is used extensively for pre-surgical functional mapping. However, it is crucial for favorable neurosurgical outcome to delineate also fiber-tracks spreading in vicinity of brain lesion. The objects of this study were to combine diffusion tensor imaging (DTI) and fMRI for 3D visualization of motor functionality and related connectivity in vicinity of discrete brain lesions. The combination of fMRI and DTI based fiber tracking provides valuable functional information that cannot be extracted from each method separately. The use of three-dimensional visualization is crucial for understanding the spatial relation between the tumor, critical neuronal activations and fiber tracks.

Introduction

fMRI has been used in neurosurgery in order to reduce the need for invasive functional brain mapping techniques such as the pre-operative Wada test and the intra-operative electrophysiological stimulation test. The regional signal obtained in fMRI represents neuronal population response to a specific task (i.e. gray matter activation). Nevertheless, it does not provide any information about the integrity and connectivity of nerve fibers that might be related to this activation. However, brain surgery often requires intervention within fiber bundles at the vicinity and surround the lesion, thus could lead to functional deficits due to interference with vital connectivity rather than effect on the neuronal substrate. DTI [1] is a well-established method for in-vivo mapping of the white matter directionality and organization, but its clinical application has not been fully explored, especially in relation to functional reservoir in vicinity of brain lesion. In this work we combined fMRI and DTI based 3D fiber-tracking for comprehensive functional mapping of guided movement in the presence of various brain lesions.

Methods

20 patients were scanned for pre-surgical motor and somatosensory mapping. MRI was performed on a 1.5T GE MRI scanner. fMRI experiments were performed using a GE-EPI sequence with the following parameters: TR/TE=3000/55ms, matrix size=80x80, FOV=240mm^2, number of slices was 17, slice thickness was 4mm. Motor and sensory activation areas were mapped by block paradigm s that consisted of three episodes of visually guided movement of fingers, leg or mouth and caressing the palm, foot or chick, all compared to rest. DTI experiments were performed using a DWI-EPI pulse sequence with the following parameters: TR/TE=10000/98ms, Δ/δ=31/25ms, b=1000 s/mm^2 at six diffusion gradient directions [2]. 48 slices with thickness of 3mm and no gap were acquired covering the whole brain with FOV of 240 mm^2 matrix of 80x80. Fiber tracking was done similar to the FACT method as described by Mori et-al [3]. Seed ROI for visualization of the pyramidal track were taken at the level of the internal-capsule and below the M1 gray matter strip.

Results

Figure 1 demonstrates front and rear views of the pyramidal track and the fMRI activation areas of 54 years old right-handed male with a large temporo-frontal lesion diagnosed as Glioblastoma Multiforme. The motor fibers are shown in dark blue and the right hand, right leg and tongue motor activation areas are shown in magenta, orange and light pink, respectively. The T_1 Gd-enhanced area is shown in yellow and will be referred to as the core of lesion, the rest of the T_2 hyperintensity area is shown in off-white and is suspected as edematous tissue. Figure 1A demonstrates that although fMRI indicated mouth activation within the edematous tissue, DTI did not detect fibers approaching this locus of activation. Figure 1B shows a blow-up of the rear view of the brain. In oppose to the lack of facial motor connection, the hand and leg motor fibers passing through the medial part of the lesion seems to be intact.

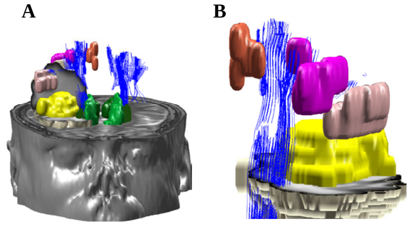

Figure 1

Figure 2 depicts rear (2A) and top (2B) views of the pyramidal track and the fMRI activation areas of 47 years old right handed female with a space-occupying lesion in the right fronto-parietal region, most probably cavernoma. The lesion is shown in yellow, the sensory and motor fibers are shown in light and dark blue, respectively, while the left hand motor and sensory activation areas are shown in magenta and red, respectively. The motor and sensory activations of the left hand are detected superior and relatively distant from lesion (Figure 2A). Nevertheless, DTI based fiber tracking demonstrated that the lateral side of the right pyramidal tract is at close proximity to the lesion at the level of the caudate nucleus (Figure 2B). It seems from a top view (Figure 2B) that the somatosensory fibers (light blue) are passing through the tumor without displacement. However, a blow up of the side view (Figures 2C and 2D) demonstrates that the sensory fibers (light blue) are intact, touching upon and maybe slightly pressed by the medial–superior borders of the tumor. Intra-operative motor stimulation showed that the lesion was indeed approximating the medial part of the motor tract.

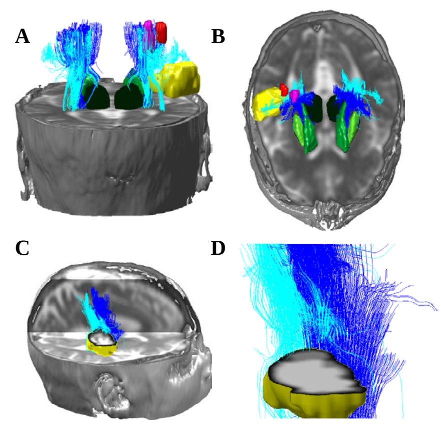

Figure 2

Discussion

There are three ways in which a tumor or a lesion can affect white matter fibers: destruction, displacement or infiltration. In the first patient the core of the tumor seems to be lateral to the pyramidal track fibers and does not involve the fibers (see yellow area in Figure 1A). Nevertheless, it is the large area of edema in this patient (off-white area in Figure 1A) that infiltrates the pyramidal track. Within the edematous tissue, the fibers seem to be disrupted yet the lack of tongue motor deficit does not support this finding. It is known that edema reduces the diffusion anisotropy. Therefore in edematous region, the destructed white matter fibers as detected by DTI alone might be artifactual and may not reflect real pathophysiological state of the white matter.

In the second patient, motor activation regions as seen in fMRI, appear distant from the lesion. Based on fMRI data only, the surgeon might conclude that by careful dissection, so to avoid the activated regions, no motor deficits will occur with the removal of the tumor. However, DTI showed, that the tumor is in close proximity of less than 2 mm to the pyramidal track fiber (somato-sensory and motor) above the caudate head (Figure 2C-D). Removal of the tumor in this case might result in cutting of the lateral aspect of fibers that seem to be crucial for intact motor and somatosensory function. .

Conclusion

The two cases presented here show the enhanced utility of combined fMRI and DTI in 3D visualization. In the first case, fMRI activations enhanced the validity of mapping by overcoming the limitation of DTI to imply functionality in areas of severe edema. In contrast in the second case, fMRI demonstrated gray matter activation that are far from the lesion. Nevertheless, DTI enhanced the sensitivity of functional mapping by delineating fiber tracks that approximate the tumor. This added mapping provided critical information regarding the functional hazard when approaching the lesion at this anatomical level. Both cases demonstrate that the combined approach of fMRI-DTI when visualized in 3D can enhance the sensitivity and validity of pre-surgical mapping.

References

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