Intracranial vascular malformations: Tractography reveals motor pathway anatomy and integrity

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Introduction

The surgical treatment of intracranial vascular malformations, including the evacuation of associated haematomas and definitive excision of the primary lesion, carries a significant risk of morbidity and mortality. Surgical trauma to eloquent white matter pathways may lead to serious neurological deficit, furthermore endovascular embolisation techniques and stereotactic radiosurgery also risk injury to the eloquent white matter pathways, secondary to ischaemia, haemorrhage or radio-necrosis. CT, MRI and angiography are used in the investigation of patients with intracranial vascular malformations. However, a major disadvantage of these imaging modalities is that they are unable to adequately identify and display the position of the eloquent white matter pathways of the brain. Diffusion tensor tractography is an imaging technique which allows the identification and visualisation of the white matter pathways in the living human brain [1] and has recently been applied to a number of patients with intracranial vascular malformations [2-4]. In this study we have applied a novel semi-automated streamline tractography technique [5] for the rapid visualisation of the motor pathways in patients with both haemorrhagic and non-haemorrhagic intracranial vascular malformations.

Methods

Patients Between March 2004 and March 2005 a prospective study of patients 16 years or older with proven supratentorial intracranial vascular malformation was undertaken. The study was approved by the regional ethics committee and all patients gave their written informed consent.

MRI data acquisition All patients were scanned on a 1.5 T General Electric Signa MRI system. DTI was achieved using a single shot echo planar sequence (EPI) with 12 diffusion sensitised directions as described previously [1]. In plane resolution was 2.5mm and through plane resolution was 2.8mm, providing near isotropic voxels. The diffusion tensor was determined for each image voxel and the tensor was diagonalised.

Fibre Tracking Whole brain subvoxel tractography was performed by interpolation of the diffusion tensor image as described previously [1]. Tractography was initiated from the centre of every voxel with a FA value greater than 0.05 and proceeded through the image data with a step length of 1.0 mm. Streamlines were terminated at the FA threshold value of 0.05, no angular threshold was applied. A single voxel was chosen bilaterally within the anterior medulla, each voxel was chosen simply as being that voxel centrally placed within the area of high fractional anisotropy (FA) in that region. This particular voxel was specified as our initial studies, on ten normal volunteers, indicated that voxels chosen from this location consistently reproduced a clear representation of the motor pathways. The geometry of the streamlines reconstructed for both of these selected voxels was compared with every other streamline throughout the entire image. Those streamlines geometrically similar were grouped together to reconstruct the motor pathways. This technique is similar to a technique we have previously presented [5].

Results

We identified the descending motor pathways in 6 patients with intracranial vascular malformations. Of these patients 4 presented with a spontaneous intracranial haemorrhage, 2 of whom were clinically hemiparetic on examination. ***Patients 1 and 2*** (figure 1) presented with seizures. There was no haemorrhage associated with their intracranial vascular malformations and neither patient demonstrated loss of motor function on examination. Tractography clearly demonstrated that their motor pathways were structurally intact. ***Patients 3 and 4*** (figure 2) presented with headache and were found to have large intracerebral haematomas associated with their vascular malformations. Neurological examination of both patients revealed no motor deficit. Tractography revealed displaced although structurally intact motor pathways. ***Patient 5*** (figure 3) presented with a mild right upper limb weakness consequent to a haemorrhage from a large cavernous malformation. Tractography revealed the left motor pathway to be slightly disrupted of a reduced volume and an aberrant trajectory. ***Patient 6*** (figure 3) presented with a right sided hemiplegia and reduced conscious level consequent to a large intracerebral haematoma from a small parafalcine AVM. Following evacuation of this haematoma the hemiplegia failed to improve, subsequent tractography was unable to visualise the left motor pathway. The FA along the expected trajectory of the left motor pathway was clearly reduced suggestive of Wallerian degeneration of the tract (figure 3 D_6) [6].

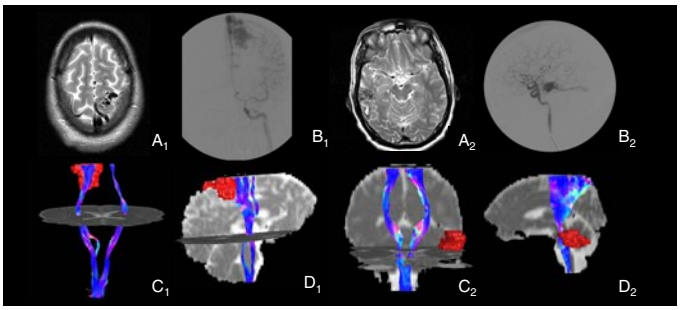

Figure 1

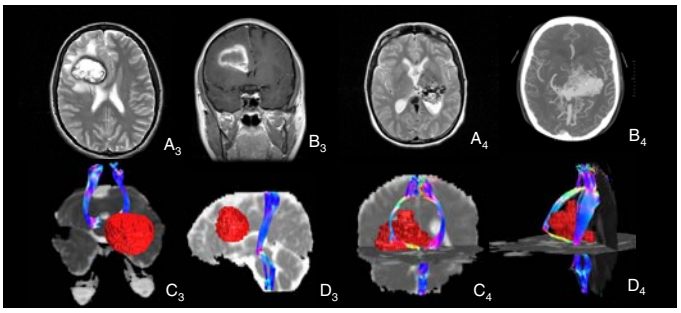

Figure 2

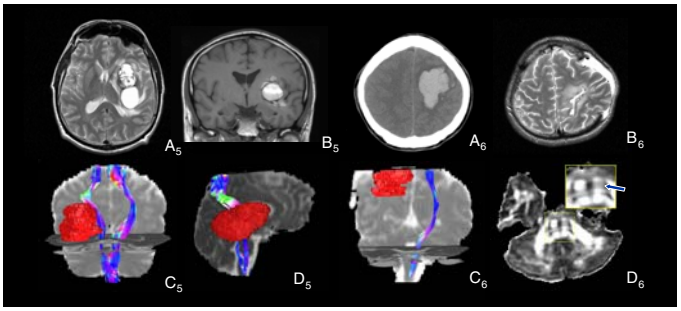

Figure 3

Discussion

Our semiautomatic streamline tractography algorithm reliably and consistently reconstructed and visualised the location of the descending motor pathways in all 6 patients with intracranial vascular malformations (with the exception of patient 6 due to presumed Wallerian degeneration). This is the first time this has been demonstrated for both haemorrhagic AVMs and cavernous malformations, conditions where surgical evacuation of the haematoma and excision of the underlying vascular abnormality are often indicated. In all cases where motor function was intact or mildly impaired, the technique was able to clearly delineate the motor pathways, even in the presence of large anatomic displacement from the vascular abnormality or associated haemorrhage. We have shown that the integrity of the motor pathway demonstrated with tractography corresponds to the presence of clinical deficit. The incorporation of this tractography data into neurosurgical navigation systems may allow the intraoperative localisation of the motor pathways reducing further the risks of surgical injury and neurological deficit. These data may also be incorporated into radiotherapy planning protocols potentially reducing the risk of symptomatic radio-necrosis by limiting the dosage applied to the eloquent motor pathways.

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