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Lack of the cerebral peduncle involvement in a series of adult supratentorial AVM: A diffusion tensor imaging study

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ABSTRACT

Congenital as arteriovenous malformation(AVM) is, most patients with AVM would be asymptomatic until adults. During the past 2 years, 23 cases of adult supratentorial AVM patients had DTI after admission. The region of interest was placed in the cerebral peduncle. Their FA value and fiber number was compared with those of cavernous malformation (CM) and tumor (glioma and meningioma). In the AVM group, there was no significant difference in FA of the cerebral peduncle (ipsilateral 0.758 ± 0.055 versus contralateral 0.755 ± 0.049; $P > 0.05$) and fiber number (319.6 ± 82.9 versus 304.7 ± 89.1; $P > 0.05$). In the CM group, FA of the cerebral peduncle on ipsilateral side (0.711 ± 0.092) was significantly lower than that of contralateral side (0.768 ± 0.043) ($P < 0.01$). Similar result was in fiber number of the CM group (251 ± 82.1 versus 307.3 ± 77.0; $P < 0.05$). In tumor group, FA of ipsilateral side (0.713 ± 0.084) was lower than that of contralateral (0.751 ± 0.052) without significant difference. There was no significant difference in fiber number between ipsilateral and contralateral sides in the tumor group (308.9 ± 112.4 versus 287.9 ± 62.4). Unlike non-AVM lesions (CM and tumor), FA value and fiber number of the ipsilateral cerebral peduncle is less influenced in the AVM group. The lack of the cerebral peduncle involvement indicates that there is plasticity of white matter in AVM.

Cerebral arteriovenous malformation (AVM) is usually thought to be congenital. There were few reports that AVM is de novo [9] or regresses spontaneously [3]. Hemorrhage, headache, and seizure are the three common presentations in cerebral AVM [36]. But most patients with AVM would be asymptomatic until adults.

Fractional anisotropy (FA) has been used to characterize water diffusion anisotropy of brain in diffusion tensor imaging (DTI). FA depends on organization and myelination of nerve tract [7,8]. Thus, DTI measurements of the cerebral peduncle may be used to characterize microstructure abnormalities in AVM and non-AVM lesions. In the present study, we aimed at investigating the cerebral peduncle involvement in AVM and non-AVM lesions using DTI.

During the past 2 years, there were 51 cases of adult with supratentorial lesions, including AVM, cavernous malformation (CM) and tumor (glioma and meningioma), who had DTI after admission. The mean age of the AVM group ($n = 23$) was 33.6 years (range: 21–51 years). Cases of CM ($n = 14$; mean age 37.4 years; range: 20–57 years) and tumors ($n = 14$, 10 cases of glioma and 4 cases of meningioma; mean age 46.1 years; range: 24–63 years) were used as control. The ratio of male to female was 15:8, 9:5, and 10:4, respectively. All lesions were solitary without involvements of the corpus callosum and the midbrain. Except two patients (one in the AVM group and one in CM) who could not accept surgical risks, 49 patients underwent operation with informed consent, whose diagnoses were confirmed by histology.

On a Siemens 3.0 Tesla MRI Scanner, the diffusion-weighted data were acquired using a single-shot spin-echo diffusion sensitized echo-planar imaging (EPI) sequence with 12 encoding directions, a diffusion sensitization of $b = 1000\,s/mm^2$, TR of 3 s, and TE of 93 ms. EPI image distortion artifacts were reduced using GRRAPA with acceleration factor or k-space undersampling of $R = 2$. The slice thickness was 4 mm with 22 axial slices covering the whole brain (foramen magnum to vertex), a field of view of 220 mm × 220 mm, and an image matrix of 128 × 128 that matched sequences described above. The number of image averages was 4. The total DTI acquisition time was approximately 2.8 min.

All of the image processing was performed using the software MedINRIA (http://www-sop.inria.fr/asclepios/software/MedINRIA). Regions of interest (ROI) were selected according to FA maps. First, we determined the image with the highest FA value of the cerebral peduncle in the axial plane FA maps. Then a 3 × 3 voxels ROI was placed in the cerebral peduncle to produce the highest average FA value (Fig. 1). The number of fibers through the ROI was calculated using the software. The FA threshold value was 0.20 to keep tracking based on the connectivity of the neighborhood.

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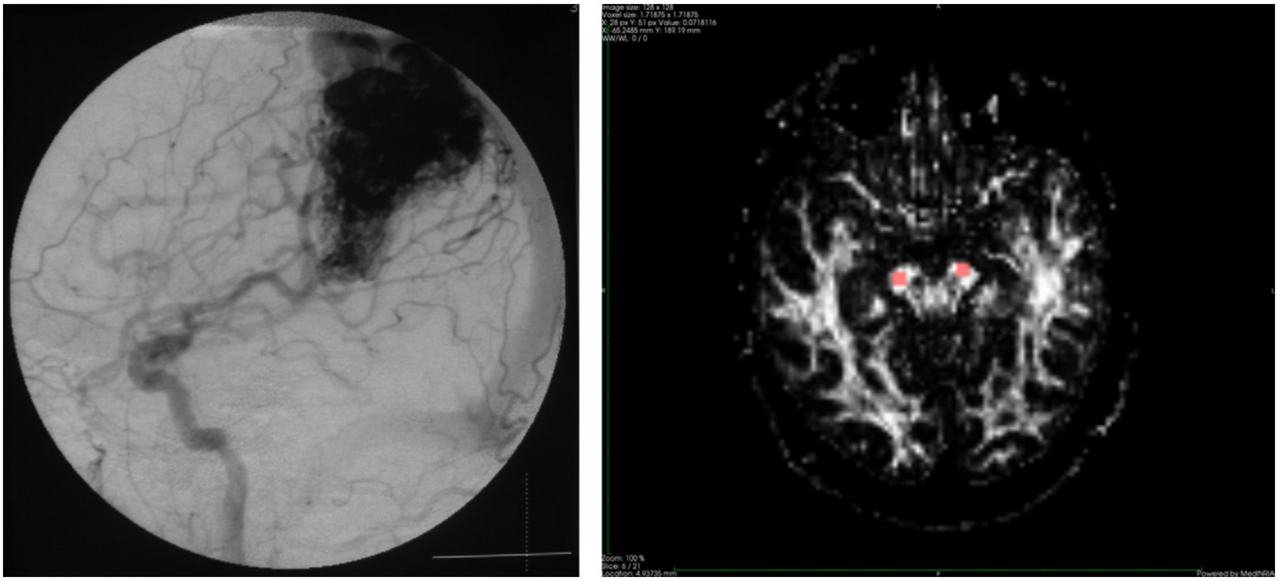

Fig. 1. Selection of the ROI in FA map. Angiography demonstrates a case of arteriovenous malformation (AVM) in the left parieto-occipital lobe (on the left). Region of interest (ROI) (in red) is placed in the cerebral peduncles in fractional anisotropy (FA) map (on the right). The FA was 0.798 in the ipsilateral cerebral peduncle and 0.799 in the contralateral cerebral peduncle.

All data are presented as means ± SD and compared using *t* test. Differences were considered statistically significant at a P value <0.05.

In the AVM group, the complaints were epilepsy (11 cases), headache (8 cases) and neurological deficit (5 cases). In the CM group, the complaints included neurological deficit (7 cases), headache (3 cases), epilepsy (3 cases) and asymptomatic (1 case). In the tumor (glioma and meningioma) group, patients exhibited neurological deficit (6 cases), headache (4 cases), epilepsy (4 cases) and asymptomatic (1 case). The maximum diameter of lesions was 33.9 ± 11.3 mm (range: 18–55 mm) in the AVM group, 32.2 ± 11.2 mm (14–60 mm) in the CM group and 40.9 ± 15.3 mm (22–67 mm) in the tumor group.

In the AVM group, there was no statistically difference between mean FA of the ipsilateral cerebral peduncle (0.758 ± 0.055) and that of the contralateral cerebral peduncle (0.755 ± 0.049) (P > 0.05). In the tumor group, mean FA was 0.713 ± 0.084 of the ipsilateral cerebral peduncle and 0.751 ± 0.052 of the contralateral cerebral peduncle (P > 0.05). In the CM group, the FA measured in the ipsilateral cerebral peduncle (0.711 ± 0.092) was significantly (P < 0.01) lower as compared with the contralateral cerebral peduncle (0.768 ± 0.043). A significant reduction was also observed in the ipsilateral FA of non-AVM lesions (the CM group and the tumor group) as compared to that of AVM (P < 0.05). But there were no statistically differences in the contralateral FA between groups (Fig. 2).

The potential effects of age, sex, side and lesion location on the DTI measurements were also investigated. All patients (mean age 38.1 ± 11.9 years, n = 51) were divided into four groups according to their age (<31 years, 31–40 years, 41–50 years, and >50 years). Mean FA of the contralateral cerebral peduncle was 0.771 ± 0.044 (n = 14), 0.744 ± 0.049 (n = 19), 0.771 ± 0.042 (n = 8) and 0.752 ± 0.055 (n = 10), respectively. There was no significant difference between groups (P > 0.05). The mean FA of the contralateral cerebral peduncle was 0.760 ± 0.043 in male (n = 34) and 0.752 ± 0.057 in female (n = 17) without statistically difference (P > 0.05). Whether the side was the left (0.753 ± 0.050, n = 30) or the right (0.763 ± 0.045, n = 21) did not affect the FA value of the contralateral cerebral peduncle (Fig. 3). There were 8 cases of AVM and 4 cases of CM that involved temporal lobe. The FA of the cerebral peduncle was 0.786 ± 0.048 on ipsilateral side and 0.744 ± 0.056 on contralateral side in the temporal lobe AVM group. In the temporal lobe CM group, FA was 0.727 ± 0.022 and 0.770 ± 0.015, respectively. There was significant difference between bilateral side in the temporal lobe CM (P < 0.05), but not in the temporal lobe AVM (P > 0.05). By comparing the results of ipsilateral side, the difference between the temporal lobe AVM and CM was statistically significant (P < 0.05). No contralateral side difference was found between (P > 0.05) the temporal lobe AVM and CM (Fig. 3).

In the AVM group, the number of fibers through the ROI was 319.6 ± 82.9 on ipsilateral side and 304.7 ± 89.1 on contralateral side (P > 0.05). In the CM group, fiber number of ipsilateral side (251 ± 82.1) was significantly lower than that of contralateral side (307.3 ± 77.0) (P < 0.05). In tumor, fiber number was 308.9 ± 112.4 and 287.9 ± 62.4 without significant difference between bilateral side (P > 0.05) (Fig. 4).

In literatures, DTI had been used in the evaluation of AVM surgery and radiotherapy. DTI could demonstrate the relationship of nerve tracts with AVM [12,17,33]. Some nerve tracts were less

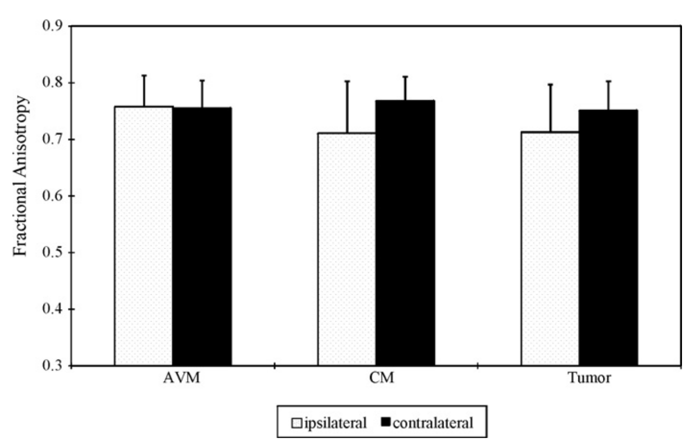

Fig. 2. FA of the cerebral peduncle in the AVM, cavernous malformation (CM) and tumor group. In the AVM group, FA of the cerebral peduncle is 0.758 ± 0.055 on ipsilateral side and 0.755 ± 0.049 on contralateral side. In the CM group, FA is 0.711 ± 0.092 and 0.768 ± 0.043. In the tumor group, FA is 0.713 ± 0.084 and 0.751 ± 0.052. There is significantly difference between bilateral side in the CM group (P < 0.01), but not in AVM or tumor (P > 0.05).

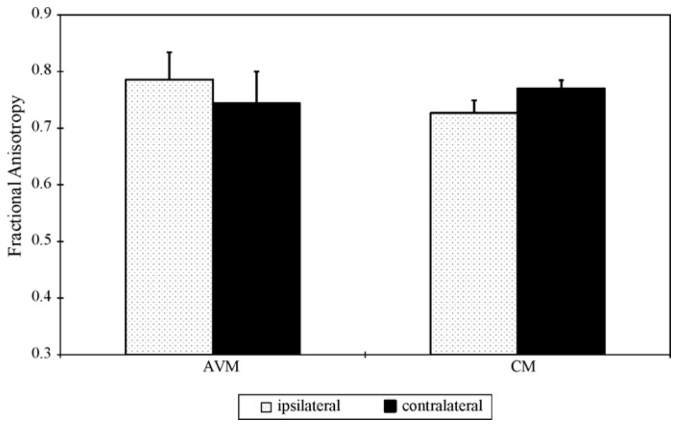

Fig. 3. FA of the temporal lobe AVM and CM. The mean FA of the temporal lobe AVM group is 0.786 ± 0.048 on ipsilateral side and 0.744 ± 0.056 on contralateral side. In the CM group, FA is 0.727 ± 0.022 and 0.770 ± 0.015. There is significant difference between bilateral side in CM ($P < 0.05$), but not in AVM ($P > 0.05$). By comparing the results of ispilateral side, there is significant difference between CM and AVM ($P < 0.05$). No difference exists on contralateral side between CM and AVM ($P > 0.05$).

visualized in patients with neurological symptoms than in asymptomatic AVM patients [5,23]. The tolerant dosage of radiotherapy varied in white matter [20–22]. It was DTI-guided navigation combined with other techniques that made AVM removal safer [4,13].

Influence of age on FA had been reported. FA increased in pyramidal tract and corpus callosum not only in fetuses [6] but also in healthy neonates [8]. In adult, age had significant negative correlation with FA in the genu, rostral body and isthmus [24]. However, the difference among the contralateral cerebral peduncle was not statistically significant in this series, which was consistent with the findings in healthy volunteers [34]. Another explanation was relatively small subject number in our study.

The decrease in FA was reported in Wallerian degeneration, which might be caused by infarction [19,29,35], cervical spinal cord injury [10] and neurodegenerative disease [14]. Intracranial hemorrhage [16], trauma [27], chronic subdural hemorrhage [34] and subtotal hemispherectomy [32] had been associated with the decrease in FA of the affected pyramidal tract.

It had been reported that the brain was able to compensate for the functional deficits, that is, brain plasticity, which could be revealed by fMRI. In 1999, Kombos et al. [15] reported a case

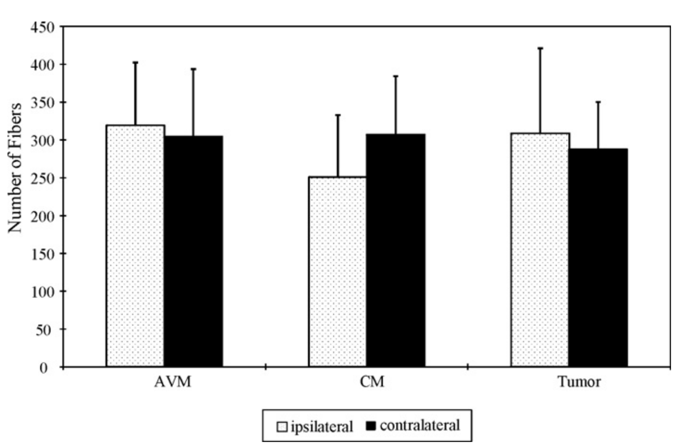

Fig. 4. Number of fibers through the ROI in the AVM, cavernous malformation (CM) and tumor group. In AVM, fiber number of the cerebral peduncle is 319.6 ± 82.9 on ipsilateral side and 304.7 ± 89.1 on contralateral side. In CM, number is 251 ± 82.1 and 307.3 ± 77.0. In tumor, number is 308.9 ± 112.4 and 287.9 ± 62.4. There is significantly difference between bilateral side in the CM group ($P < 0.05$), but not in AVM or tumor ($P > 0.05$).

of AVM with shift of motor region. Alkadhi et al. [1] found that cerebral AVM led to reorganization within the somatotopic representation in cortex and to occasional abnormal expansion into nonprimary motor areas. Odzdoba et al. [25] reported abnormal cortical activation patterns in AVM and shifts in the activation pattern after endovascular procedures. Even language network shift had been reported in stroke and AVM patients. Guzzetta et al. [11] found in left perinatal stroke patients had extraordinary organizational language capabilities. Vikingstad et al. [31] reported the right hemisphere-shifted language network in the AVM group. The reliability of fMRI in the AVM had been questioned, for the hemodynamic perturbations in AVMs might impede the fMRI signal, such as in perilesional eloquent cortex [30] and language reorganization [18]. But Thickbroom et al. [28] reported the fMRI signal magnitude was not significantly affected in AVM.

The plasticity of white matter had also been reported. In the multiple sclerosis patients, there were a significantly larger number of connections between the left and right thalami than in the control subjects [2]. Ramu et al. [26] had discovered the brain fiber tract plasticity in experimental spinal cord injury.

Our results show the ipsilateral FA of the cerebral peduncle appears to be less influenced in AVM than in CM and tumor. And this difference was not associated with age, sex, side and location of lesion. The findings indicated that possible plasticity of fiber tracts, which might be secondary to cortical plasticity in AVM as demonstrated by fMRI. And white matter plasticity differed in AVM, CM and tumor, as showed by difference in FA value and fiber number in every group. It could be partly explained by our findings that most patients with congenital AVM were asymptomatic until adults.

There was the partial volume effect in DTI and heterogeneity in each group. It was reasonable that the smaller voxel size would provide more detailed information. Given the small number of subjects reported in this preliminary study, future research should assess the findings in a larger group of patients with smaller voxel size and more homogeneity in groups.

The results from this study demonstrate that FA value and fiber number of the cerebral peduncle is less affected in AVM than in non-AVM lesions. The lack of the cerebral peduncle involvement revealed by DTI indicates plasticity of white matter in AVM, which is in keeping with observations from studies of the plasticity of cortex in AVM by fMRI.

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