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FUNCTIONAL REORGANIZATION OF THE PRIMARY MOTOR CORTEX IN A PATIENT WITH A LARGE ARTERIOVENOUS MALFORMATION INVOLVING THE PRECENTRAL GYRUS

Milan Radoš[1]*,
Ines Nikić[1],
Marko Radoš[2],
Ivica Kostović[1],
Patrick R. Hof[3],
Goran Šimić[1]

[1]*Department of Neuroscience, Croatian Institute for Brain Research, University of Zagreb Medical School, Zagreb, Croatia*

[2]*Department of Clinical and Interventional Radiology, Clinical Hospital Center Zagreb, University of Zagreb School of Medicine, Zagreb, Croatia*

[3]*Fishberg Department of Neuroscience and Friedman Brain Institute, Icahn School of Medicine at Mount Sinai, New York, USA*

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Abstract

It is known that the brain can compensate for deficits induced by acquired and developmental lesions through functional reorganization of the remaining parenchyma. Arteriovenous malformations (AVM) usually appear prenatally before a functional regional organization of the brain is fully established and patients generally do not present with motor deficits even when the AVM is located in the primary motor area indicating the redistribution of functions in cortical areas that are not pathologically altered. Here we present reorganization of the motor cortex in a patient with a large AVM involving most of the left parietal lobe and the paramedian part of the left precentral gyrus that is responsible for controlling the muscles of the lower limbs. Functional MRI showed that movements of both the right and left feet activated only the primary motor cortex in the right hemisphere, while there was no activation in the left motor cortex. This suggests that complete ipsilateral control over the movements of the right foot had been established in this patient. A reconstruction of the corticospinal tract using diffusion tensor imaging showed a near-complete absence of corticospinal fibers from the part of the left precentral gyrus affected by the AVM. From this clinical presentation it can be concluded that full compensation of motor deficits had occurred by redistributing function to the corresponding motor area of the contralateral hemisphere.

Keywords

• Arteriovenous malformation • Neuroplasticity • fMRI • Ipsilateral corticospinal tract

Introduction

The brain shows significant capacities for functional restructuring and reorganization in case of developmental and acquired lesions whereby an healthy part of parenchyma assumes the functions of the impaired structures [1,2]. This functional reorganization ability is especially evident for lesions that occur during early prenatal development, so that substantial structural changes often have a very discrete or absent clinical presentation. Arteriovenous malformations (AVM) result from abnormal angiogenesis likely in the early stage of prenatal brain development, and are due to direct, abnormal connections of arteries and veins [3-5]. Patients with AVM may present with different clinical symptoms, most frequently in the form of epilepsy, although many patients who have no symptoms regardless of the location of the AVM [6,7]. As such, asymptomatic patients most likely have functional reorganization, which in turn becomes important for treatment decisions of these AVM. Functional magnetic resonance imaging (fMRI) is a noninvasive method that can show how the regional brain activity changes during specific tasks and it is therefore suitable for studying functional reorganization in patients with AVM [8-10].

We present the clinical case of a young woman with a large AVM affecting almost the entire left parietal lobe and the paramedian part of the left precentral gyrus. Despite the fact that pathologically altered parenchyma also included the area of the primary motor cortex that controls the movements of the contralateral lower limb, the patient had no motor deficits. We used fMRI to examine how the impairment of the primary motor cortex was functionally compensated, and which part of the brain had taken over the function of the damaged part of the left precentral gyrus. Furthermore, both corticospinal tracts were reconstructed to show the impact of brain damage on the development of neural connections between the cortex and relevant subcortical structures [11].

The main objective of this study was to assess whether the cortical reorganization of the primary motor cortex involved repurposing of the secondary motor area ipsilateral to the AVM or whether the contralateral motor cortex had taken the function over [7,12].

Material and methods

The patient was 27 years old woman who recently experienced a first grand-mal epileptic seizure. A brain structural MR examination revealed a large AVM (grade V according to Martin-Spetzler classification [13]), which involved most of the left parietal lobe and the paramedian part of the precentral gyrus. The patient had suffered no neurological deficits prior to the occurrence of the epileptic seizure. The patient was informed about potential risks in case of neurosurgical or endovascular intervention and she opted to receive only symptomatic antiepileptic therapy without any invasive procedures.

MR imaging was performed on 3 T MR scanner (Magnetom TrioTim, Siemens,

* *E-mail: mrados3@yahoo.com*

Germany) using a 12-channels head coil. Standard sets of sequences were obtained together with a high-resolution T1 MPRAGE sequence (TR = 2300 ms; TE = 3.05 ms; flip angle = 9°; voxel size = 1x1x1 mm) for structural analysis. fMRI was performed in a block design, using a motor toes-flexion paradigm separately for the left and right feet. A gradient-echo EPI sequence sensitive for blood oxygen level-dependent (BOLD) contrast was aplied (TR = 3000 ms, TE = 31 ms, flip angle = 90°, resolution = 3x3x3.2 mm). The fMRI study consisted of alternating 30-s periods of rest and repeated flexion of the foot toes for a total scan time of 3 minutes. Diffusion tensor imaging (DTI) was also performed (TR = 4500 ms; TE = 94 ms; flip angle = 90°; number of directions = 30; voxel size = 1.6x1.6x3 mm; number of averages = 4). Siemens Neuro3D software was used for evaluation of activation zones from fMRI scans and for reconstruction of corticospinal tracts from DTI scans.

Results

The analysis of the fMRI scans in a block-design paradigm showed that flexion of the left foot toes elicited expected activation in the paramedian part of the right precentral gyrus and in the neighboring premotor area (Figure 1). During flexion of the right foot toes, the activation also occured in the right paramedian part of the precentral gyrus and neighboring premotor area, almost in the same location as where the activation occurred during motion of the left toes.

A comparison of the activation zones clearly showed that the same area of the primary motor cortex in the right precentral gyrus was responsible for motor control of both left and right toes. The reconstruction of the left corticospinal tract revealed a near complete attrition of the fibers from the paramedian part of the left precentral gyrus, whereas fibers originating more laterally the left precentral gyrus — a region that was not activated during flexion of the right toes — were preserved (Figure 1).

Discussion

AVM develop mostly in the embryonic period before distribution of function in the brain is established [5]. They are composed of a vascular conglomerate in which the arterial and venous vasculature is directly connected, with no appearance of functional parenchyma in the AVM itself. Previous studies have demonstrated that even when the AVM is located in the primary motor cortex, frequently no motor deficits

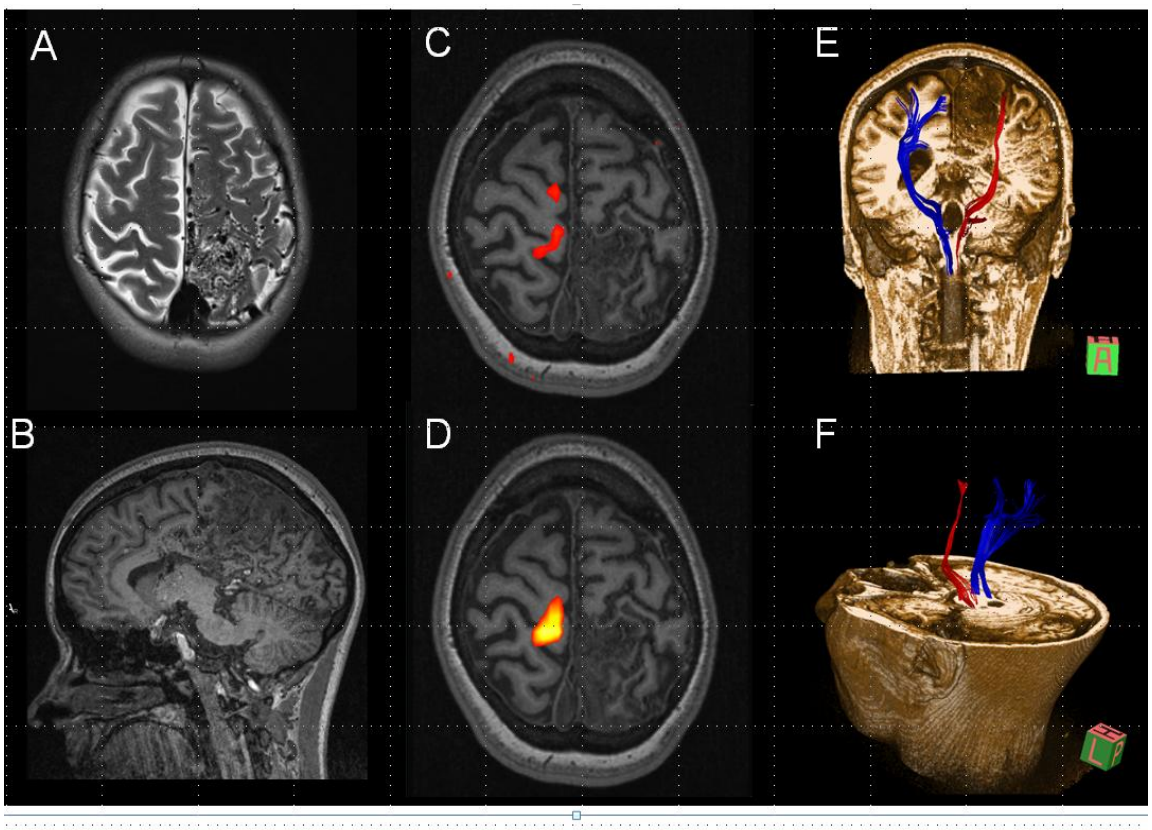

Figure 1. A. T2-axial section of the brain display a large AVM, anteriorly affecting the paramedian part of the left precentral gyrus.
B. T1-sagittal section of the brain with the AVM affecting most of the left parietal lobe.
C. Activation zones in the right primary motor and premotor cortex during flexion of the right foot toes.
D. Activation zones in the right primary motor and premotor cortex during flexion of the left foot toes.
E and F. Reconstructed corticospinal tracts; red, left corticospinal tract, and blue, right corticospinal tract. Note that the left corticospinal tract is thinner than the right and that fibers from the paramedian part of the left precentral gyrus are completely absent.

are found, due to functional reorganization of the remaining cortex [6,7]. Owing to the high risk of rupture, which can be fatal, AVM are very often treated neurosurgically, either endovascularly, with gamma-knife radiation, or with a combination of these therapeutic approaches [14,15]. It is extremely important to know how the remaining cortex is functionally reorganized, in order to determine the extent of the therapeutic intervention and to prevent the emergence of new neurological complications after the treatment of the AVM [7,9,16].

Non-invasive fMRI plays a key role in the clinical investigation of patients with AVM as it provides functional mapping of the entire brain, which represents a major advantage over direct intraoperative cortical stimulation that only enables examination of the cortex directly below the area of craniotomy [17].

Because fMRI depends on hemodynamic changes that occur during cortical activation, there is a theoretical risk that, due to the proximity of an AVM, as well as the altered perfusion pattern surrounding it, the registration of the signal on BOLD sequences may be absent leading to misinterpretation [18,19]. However, previous studies have shown that even in the immediate proximity of an AVM it is possible to register hemodynamic changes associated with cortical activation [20]. In our patient, the finding of a predominantly ipsilateral activation during flexion of the right foot toes, indicates that the motor cortex of the unaffected hemisphere took over the function of the affected precentral gyrus on the contralateral side. This functional reorganization indicates a dominantly ipsilateral control of the foot motion.

It has previously been shown that about 10% of the fibers of the corticospinal tract descend on the ipsilateral side, and a part of them terminates in Rexed laminae VIII on the same side [21,22]. However, under normal circumstances, it appears that this path does not have a significant role in motor control as revealed in experiments in macaque monkeys in which stimulation of the primary motor cortex did not result in a significant response of the ipsilateral motor neurons [23]. However, after injury of the contralateral primary motor area, activation of the ipsilateral primary motor cortex became crucial during recovery [23-25]. This phenomenon was interpreted as the emergence of new synaptic connections between alpha motor neurons of the spinal cord and descending ipsilateral and contralateral pathways originating in the ipsilateral primary motor cortex [26].

The activity of the ipsilateral pathway that is present at birth is gradually reduced until the 10th year of life when ipsilateral muscle evoked potential cannot be induced any longer by transcranial magnetic stimulation, most likely due to increased inhibitory effect of transcallosal fibers [1,2,27,28]. It is reasonable to assume that a physiological decrease in the function of the ipsilateral pathways does not occur in case of developmental anomalies affecting the primary motor cortex, which rather result in an ipsilateral pathway gain-of-function and hypertrophy [29,30].

The results of our study clearly show that the pattern of activation in motor control of both feet was elicited only in the right precentral gyrus, which can be interpreted as a consequence of retaining an early ontogenetic organization of the corticospinal tract with a functional ipsilateral component [1,2,29,30]. The influence of the ipsilateral corticospinal tract in our patient is further enhanced by the absence of inhibitory transcallosal fibers that normally arise from the contralateral primary motor area, which was pathologically altered by the AVM. In fact, DTI revealed that the fibers from the left paramedian part of the precentral gyrus were entirely absent, due to the AVM. Therefore, there were neither corticospinal fibers to control the movements of the foot, nor transcallosal inhibitory effect on the contralateral primary motor cortex [24], in this patient.

This study reveals the occurrence of early and remarkable compensatory neuroplasticity of the motor cortex and the ability to transfer the function of impaired primary motor cortex to the homologous cortical domain of the contralateral hemisphere to allow for muscle control via the ipsilateral corticospinal tract.

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