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Original contribution

Comparison of 7 T and 3 T MRI in patients with moyamoya disease

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ABSTRACT

Magnetic resonance imaging and magnetic resonance angiography (MRI/MRA) are widely used for evaluating the moyamoya disease (MMD). This study compared the diagnostic accuracy of 7 Tesla (T) and 3 T MRI/MRA in MMD. In this case control study, 12 patients [median age: 34 years; range (10–66 years)] with MMD and 12 healthy controls [median age: 25 years; range (22–59 years)] underwent both 7 T and 3 T MRI/MRA. To evaluate the accuracy of MRI/MRA in MMD, five criteria were compared between imaging systems of 7 T and 3 T: Suzuki grading system, internal carotid artery (ICA) diameter, ivy sign, flow void of the basal ganglia on T2-weighted images, and high signal intensity areas of the basal ganglia on time-of-flight (TOF) source images. No difference was observed between 7 T and 3 T MRI/MRA in Suzuki stage, ICA diameter, and ivy sign score; while, 7 T MRI/MRA showed a higher detection rate in the flow void on T2-weighted images and TOF source images ($p < 0.001$). Receiver operating characteristic curves of both T2 and TOF criteria showed that 7 T MRI/MRA had higher sensitivity and specificity than 3 T MRI/MRA. Our findings indicate that 7 T MRI/MRA is superior to 3 T MRI/MRA for the diagnosis of MMD in point of detecting the flow void in basal ganglia by T2-weighted and TOF images.

1. Introduction

Moyamoya disease (MMD) is a progressive steno-occlusive cerebrovascular disease with the development of rich arterial collaterals called moyamoya vessels [1–4]. Cerebral angiography is the standard diagnostic tool for MMD but is invasive and risky [5,6]. The development of magnetic resonance imaging (MRI) techniques has allowed the less invasive diagnosis of MMD when used in conjunction with magnetic resonance angiography (MRA) [7–10]. The 3.0 Tesla (T) MR technique is usually performed in clinical situations and has been known to have superiority to 1.0/1.5 T MR techniques in the diagnosis of MMD, such as moyamoya vessels and ivy signs [5,11–17]. At presents, more high-quality imaging techniques, such as 7.0 T MRI/MRA, have been developed [18]. Although these instruments are not widely accepted in a clinical setting, an increasing number of research sites have access to high-field strength MRI scanners with high signal-to-noise ratios (SNR) and contrast-to-noise ratios, as well as increased T1 relaxation compared to 3.0 T MRI [19–29]. These properties of 7.0 T MRI allow for a more precise delineation of small arteries [19,23–26]. On these bases, we hypothesized that 7.0 T MRI/MRA could be used to evaluate moyamoya vessels and ivy signs more precisely than 3.0 T MRI/MRA. While a few studies using 7.0 T MRI, have been performed for evaluate MMD [30]. Therefore, the purpose of our study was to compare the diagnostic accuracy of 7.0 T and 3.0 T MRI/MRA for evaluating MMD using five criteria.

2. Materials and methods

2.1. Patient population

All study protocols were approved by the local ethics committee, and written informed consent was obtained from all patients (IRB number: 2015-07-028).

A total of 12 patients (24 hemispheres; female: male = 6:6) who had been previously diagnosed with MMD by conventional cerebral angiography, and 12 healthy controls (24 hemispheres; female: male = 7:5) from January 2015 to June 2016 were included, retrospectively, in this case control study. The median age of the patient group, at the time MRIs were performed, was 36.0 years (range: 10–66 years). The median age of the control group was 25 years (range: 22–59 years).

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Diagnosis of MMD was based on guidelines reported by Fukui et al. [2], and patients who had any other disease related to intracranial arterial stenosis were excluded. All patients underwent 3.0 T and 7.0 T MRI/MRA, and conventional cerebral angiography within 15 days of each other. Between the three examinations, any patients did not have clinical event.

We performed conventional cerebral angiography in all MMD patients. Controls were volunteers from the local community without any cerebrovascular diseases. Both 3.0 T MRI/MRA and 7.0 T MRI/MRA were performed on all subjects. All patients underwent 3.0 T and 7.0 T MRI/MRA, and conventional cerebral angiography within 15 days of each other

2.2. Imaging protocol and parameter

Scans were acquired using a 3.0 T and 7.0 T MR system (Philips Healthcare, Cleveland, OH, USA) with a volume transmit and 16-channel receiving head coil (Nova Medical, Wilmington, MA, USA). The standard scanning protocol included a 3D TOF MRA, fluid-attenuated inversion recovery (FLAIR) image, and a T2-weighted image, which were used to assess small vessel pathology in these subjects. The following MR parameters were used for the 7.0 T scanner: 7.0 T 3D TOF MRA: TR 65 ms, TE 1.36 ms, flip angle 30°, FOV $220 \times 199 \times 144$ mm^3, matrix size 552×332, voxel size $0.4 \times 0.6 \times 0.8$ mm^3, scan time 10 min 32 s; 7.0 T T2-weighted image: TR 4745 ms, TE 53 ms, flip angle 90°, FOV $220 \times 220 \times 135$ mm^3, matrix size 368×360, voxel size $0.6 \times 0.6 \times 3.0$ mm^3, scan time 5 min 3 s; 7.0 T FLAIR image: TR 8000 ms, TE 312 ms, TI 2200 ms, FOV $220 \times 220 \times 160$ mm^3, matrix size 220×218, voxel size $1.0 \times 1.0 \times 2.0$ mm^3, scan time 4 min 40 s. The parameters for the 3.0 T scanner were as follows: 3.0 T 3D TOF MRA: TR 41 ms, TE 3.1 ms, flip angle 20°, FOV $250 \times 200 \times 96$ mm^3, matrix size 880×359, voxel size $0.28 \times 0.56 \times 1.2$ mm^3, scan time 4 min 45 s; 3.0 T T2-weighted image: TR 3200 ms, TE 80 ms, flip angle 90°, FOV $210 \times 210 \times 140$ mm^3, matrix size 420×414, voxel size $0.5 \times 0.5 \times 4.0$ mm^3, scan time 3 min 37 s; 3.0 T FLAIR image: TR 6400 ms, TE 340 ms, TI 1650 ms, FOV $224 \times 224 \times 170$ mm^3, matrix size 224×224, voxel size $1.0 \times 1.0 \times 2.0$ mm^3, scan time 6 min 38 s.

2.3. Imaging analysis

Radiological assessments were performed using the PACS digital software system (Marosis 5.4 PACS viewer; Marotech, Seoul, Korea). All 3.0 T and 7.0 T images of patients and controls were evaluated independently by two readers who were blinded to both field strength and patient group. Discrepancies between the 2 readers were resolved by consensus.

To compare the 3.0 T MRI/MRA and 7.0 T MRI/MRA systems, we used five parametric scales of MMD patients. First, we applied the Suzuki grading system [1] to each cerebral angiography, 3.0 T MRA and 7.0 T MRA, and then compared the Suzuki grades to investigate correlation differences. Suzuki angiographic progression is detailed from early carotid narrowing to the formation of basal moyamoya vessels and finally to the disappearance of these collateral vessels and maintenance of the cerebrum by the external carotid and vertebral systems. Suzuki grading was defined in six grades: Grade 1, narrowed ICA bifurcation; Grade 2, initiation of the moyamoya as dilated anterior cerebral artery (ACA) and middle cerebral artery (MCA); Grade 3, further increase in moyamoya change of the ICA bifurcation and narrowed ACA and MCA; Grade 4, moyamoya change reducing with occlusive changes in ICA; Grade 5, occlusion of ICA, ACA and MCA; Grade 6, ICA essentially disappeared.

Second, we measured the diameter of the terminal portion of ICA, and then compared measurements taken with 3.0 T with 7.0 T images across both patient groups. It is well known that in MMD, the terminal part of ICA changes its appearance. We measured the diameters of terminal portion of the ICA; C7 segment (origin from posterior communicating artery to the bifurcation of the ICA) [31] on source image of TOF MRA.

Third, we calculated the ivy sign score (0–2) [14–17] and compared scores between the 3.0 T and 7.0 T images. The ivy sign was defined as continuous or discontinuous linear high signal intensities along the cortical sulci and subarachnoid space. It is well-established that an ivy sign on FLAIR images is the result of slow-flowing engorged pial convexity vessels and thickened arachnoid membranes, which are associated with MMD. Hyperintense vessels on FLAIR are a useful non-invasive method for assessing intracerebral collaterals. Ivy sign score was classified as “absent (0),” “minimal to moderate (1),” and “marked (2).”

Finally, we measured abnormal vascular networks in the basal ganglia using two different methods: 1) the number of flow void signals on T2-weighted axial MR images and 2) the number of high signal intensity areas in the basal ganglia on source images from TOF MRA [12,13]. The control group was recruited to establish a normal scale against which to compare the MMD patient group.

2.4. Statistical analysis

Statistical evaluations were performed using SPSS ver. 20.0 (SPSS Inc., Chicago, IL, USA.). Unpaired *t*-tests were performed to compare age and sex between patient groups. The correlation between cerebral angiography and MRA imaging with regard to Suzuki stages was evaluated with Spearman's rank correlation test. A correlation coefficient of >0.8 indicated a strong correlation, and 0.6–0.8 indicated a moderate correlation.

Paired *t*-tests were performed to compare the ICA diameter, ivy sign score, number of flow void signals on T2-weighted MR images, and number of high signal intensity areas on source images from TOF MRA for 3.0 T and 7.0 T MR images. Regarding the diagnostic accuracy of 3.0 T and 7.0 T MRI/MRA, receiver operating characteristic (ROC) curves were created. The area under the curve (AUC) and the 95% confidence interval (CI) for each technique were also calculated, as well as cut-off values for each technique, to maximize sensitivity and specificity. The T2 and TOF criteria were analyzed separately. A p value <0.05 was considered statistically significant.

3. Results

3.1. Comparison of Suzuki stage between 3 T and 7 T MRA

There was no significant difference between the Suzuki stage of 7.0 T and 3.0 T ($p = 0.213$; Table 1). The Suzuki stage of 7.0 T MRA is same with that of cerebral angiography for all patient group except only one case, but 3.0 T MRA showed overestimation for the Suzuki stage of three cases. There was a strong correlation with the Suzuki stage of cerebral angiography for both 7.0 T ($r_s = 0.995$; $p < 0.001$) and 3.0 T MRA ($r_s = 0.942$; $p < 0.001$).

3.2. Comparison of the diameter of the terminal portion of ICA between 3 T and 7 T MRA

The diameter of the terminal portion of the ICA showed the same competence in 3.0 T and 7.0 T MRA. No significant difference ($p = 0.876$) in the mean diameter of the control group was found when using 3.0 T (4.0 mm) versus 7.0 T (4.1 mm) imaging. The mean diameter of the MMD group was 1.3 mm by 3.0 T, and 1.4 mm by 7.0 T. For 7.0 T MRA, the mean diameter of the MMD group, was significantly lower ($p < 0.001$; Table 2) than that of the control group.

3.3. Comparison of the ivy sign scores using 3 T and 7 T MRI

There was no significant difference between 7.0 T and 3.0 T imaging ($p = 0.083$) with regard to the ivy sign score of the MMD group. But,