Comparative study of 4D CTA and DSA for vascular assessment in moyamoya disease

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\textbf{A R T I C L E I N F O}

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DSA
Vascular stenosis scoring
Collateral circulation evaluation

\textbf{A B S T R A C T}

\textbf{Purpose:} To evaluate the vascular stenosis and collateral circulation in moyamoya disease using 4D CTA.

\textbf{Methods:} Two neuroradiologists evaluated 4D CTA and DSA for 101 moyamoya patients. The performance of 4D CTA relative to DSA was determined using consistency checks (kappa values, 95% CI) and correlation analysis.

\textbf{Results:} The kappa values were 0.714 (modified Suzuki score), 0.846 (Houkin score), 0.594 (basilar moyamoya vessels), 0.435 (posterior circulation collaterals) and 0.591 (ECA collaterals). The correlation coefficients were 0.843, 0.872, 0.792, 0.635 and 0.797.

\textbf{Conclusions:} 4D CTA showed strong consistency and correlation with DSA in the vascular stenosis score, but was insufficient in collateral circulation evaluation.

1. Introduction

Moyamoya disease (MMD) is a rare, idiopathic, progressive disease characterized by intracranial arterial stenosis or occlusion \cite{1}. Vascular assessments in MMD mainly include the evaluation of vascular stenosis and collateral vessel formation. Currently, the diagnosis and vascular assessment of MMD mainly rely on angiography. Digital subtraction angiography (DSA), the "gold standard" for MMD diagnosis and assessment \cite{2}, provides high temporal resolution, but is invasive; therefore, it is the first choice of investigation during treatment rather than for diagnosis. Many noninvasive angiography techniques have recently been clinically applied, including CT angiography (CTA) and MR angiography (MRA) \cite{3}. With continuous developments in imaging devices and software, whole-brain 4D CTA and time-resolved MRA have been used to make up the deficiency of traditional noninvasive angiography. In particular, 4D CTA not only retains the high spatial

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resolution of traditional CTA but also possesses temporal resolution, and has high diagnostic accuracy in hemodynamics evaluations in intracranial vascular diseases, especially arteriovenous shunt diseases [4]. However, its application value in MMD remains to be fully evaluated.

We used 4D CTA to evaluate the vascular changes in MMD, including the degree of vascular stenosis and collateral circulation, as judged using the modified Suzuki score, Houkin score, the basilar or Moyamoya vessels, posterior circulation collaterals and external carotid artery (ECA) collaterals. The value of 4D CTA in MMD was ascertained using DSA as the gold standard.

2. Material and methods

The study protocol was approved by the Commission on Scientific Research of Human Subjects of our hospital. Written informed consent was obtained from all patients.

2.1. Patients

One hundred and sixty-four patients were confirmed to have MMD (DSA and clinical diagnosis) in our hospital between December 2011 and December 2014. No patients had undergone previous revascularization. The inclusion criteria were age ≥ 18 years, preoperative 4D CTA and DSA, interval between 4D CTA and DSA ≤ 1 week and no new clinical symptoms during the interval between the two examinations. The exclusion criteria were age < 18 years, contraindications to iodine contrast agents, interval between 4D CTA and DSA > 1 week or new clinical symptoms during the interval between the two examinations.

We analyzed the following descriptive data: sex, age, clinical symptoms and atherosclerosis risk factors (hypertension, diabetes, hyperlipidemia, hyperhomocysteinemia and smoking).

2.2. Imaging protocol

The 4D CTA examinations were performed on a 320-row dynamic volumetric CT scanner (Aquilion ONE; Toshiba Medical, Tokyo, Japan). Nine whole-head volumes were acquired after bolus injection of 50 mL of iodinated contrast agent (Iopamidol; Bracco Sine Pharmaceuticals, Shanghai, China) at a rate of 5 mL/s, and then 20 mL of physiological saline (0.9%) was injected at 4–5 mL/s. The CTA protocol was started 7 s after contrast fluid injection, with a high-dose volumetric scan at 310 mA, followed after 4 s by 3 scans at 150 mA, 6 scans at 300 mA, 4 scans at 150 mA, one every 2 s, at 100 mA, then by 5 scans, one every 5 s. The reconstruction thickness was 0.5 mm, and every volume data package contained 320 layers, with a total of 6080 images.

DSA was conducted on a flat-panel-detector angiography system (Artis Zee Floor, Siemens, Germany). After femoral artery puncture, bilateral super-selective catheterization of the common carotid, external carotid, internal carotid and vertebral arteries was performed, and contrast medium (Ultravist, Bayer Pharmaceuticals, Germany; 5 mL/s) was injected. Other branches were super-selected for further display if necessary. Data acquisition was performed after multi-angle visualization of the blood vessels. The imaging parameters were as follows: matrix, 1024 × 1024, field of view (FOV), 22 cm; and pixel size, 0.21 × 0.21.

2.3. Image post-processing

3D and 4D post-processing were performed to obtain VR and MIP images. All subtraction images included a total of 18 phases, such as the arterial phase, arteriovenous mixed phase and venous phase. We selected images that best displayed the effects of segmentation, cutting and reconstruction, and thus, obtained VR and MIP images of the siphon and bifurcation of the right and left internal carotid arteries, right and left anterior, middle and posterior cerebral arteries, vertebral basilar artery and circle of Willis. We saved the VR and MIP images of the circle of Willis obtained in the anteroposterior, posteroanterior, left lateral and right lateral positions in all 18 phases for further analysis. Coronal, sagittal and axial images were obtained using bilateral DSA examination of the ECA, ICA, and vertebral basilar artery and intracranial branches from the arterial phase to the late venous phase.

2.4. Image analysis

MMD was diagnosed using well-accepted criteria [5]. The diagnostic criteria on DSA were stenosis/occlusion of the terminal portion of the ICA that did or did not affect the proximal portion of the anterior or MCA; abnormal vascular network around the stenosed/occluded blood vessels; and bilateral lesions. In addition to the above criteria, the following known etiologies had to be excluded: atherosclerosis, auto-immune disease, meningitis, brain tumor, Down syndrome, neurofibromatosis, traumatic brain injuries and other causes. In patients with typical but unilateral vascular stenosis and vascular network changes, MMD was diagnosed if the other criteria were met.

2.4.1. Modified Suzuki score

We used the modified Suzuki score [6] (Table 1) to separately grade bilateral vascular changes.

2.4.2. Houkin score

In the case of the Houkin score [7] (Table 2), bilateral changes on VR and MIP images were scored separately, and MMD was classified according to the final score: 0–1 score, grade 1; 2–4 scores, grade 2; 5–7 scores, grade 3; and 8–10 scores, grade 4.

2.4.3. Collateral circulation evaluation

The basilar or Moyamoya vessels were scored according to the location of the vessels: basal ganglia region (bilateral), AComA region, MCA-ICA tip region (bilateral), PComA-PCA region (bilateral) and bilateral tip region. Each region was given a score of 1 or 0, yielding a total score of 0–8. Collaterals vessels from the posterior circulation and ECA were separately scored as follows: no obvious collaterals vessel, 0 score; unilateral collaterals vessel, 1 score; and bilateral collaterals vessels, 2 scores. In addition, we assessed any intracranial aneurysm or other abnormal cerebrovascular changes.

2.5. Statistical analysis

SPSS 18.0 and MedCalc statistical software were used. The t-test was applied for measurement data, and the chi-square test for enumeration data. P values < 0.05 indicated significant differences.

Two neuroradiologists independently evaluated the 4D CTA (volume rendering-VR and maximal intensity projection-MIP images) and DSA images obtained after post-processing and reconstruction. In the case of disagreement, they reviewed the images together to reach an agreement standard.

Table 1

Modified Suzuki score.

<table>
<thead>
<tr>
<th>Stage</th>
<th>Classification standard</th>
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<tbody>
<tr>
<td>0</td>
<td>No evidence of disease</td>
</tr>
<tr>
<td>I</td>
<td>Mild-to-moderate stenosis around ICA bifurcation with absent or slightly developed ICA MMD</td>
</tr>
<tr>
<td>II</td>
<td>Severe stenosis around the ICA bifurcation or occlusion of either proximal ACA or MCA branches with well-developed ICA MMD</td>
</tr>
<tr>
<td>III</td>
<td>Occlusion of both ACA and MCA branches with well-developed ICA MMD (only a few of anterior or MCA branches or both are faintly opacified in antegrade fashion through meshwork of ICA MMD)</td>
</tr>
<tr>
<td>IV</td>
<td>Complete occlusion of both ACA and MCA branches with absent or small amount of ICA MMD (without opacification of either ACA or MCA branches in antegrade fashion)</td>
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