Distinguishing high-flow from low-flow vascular malformations using maximum intensity projection images in dynamic magnetic resonance angiography

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Aims and objectives

There are multiple classifications for vascular abnormalities. The newest is "ISSVA classification for vascular anomalies" (Table 1) which is based on the founding biological investigation of Mulliken and Glowacki published in 1982.

More simply, malformations can be categorized as either low-flow or high-flow lesions on the basis of their hemodynamic flow characteristics. The distinction between low- and high-flow lesions is crucial because it determines appropriate patient treatment, namely sclerotherapy for low-flow lesions or embolization for high-flow lesions.

Dynamic time-resolved MR angiography has been proven to be an accurate method for distinguishing between high- and low-flow vascular malformations. However, there are several ways of identifying vascular malformations as either high flow or low flow. Some methods are based only on the determination of the time interval between the start of arterial enhancement and the onset of lesion enhancement (artery-lesion time), whereas other methods suggest that the time of maximum enhancement of the lesion is crucial. In addition, most authors have used other findings based on T₁- and T₂-weighted imaging (signal intensity, signal voids) to support the angiographic outcomes.

The aim of our study was to examine the ability to distinguish high- from low-flow lesions on the basis of the enhancement pattern on maximum intensity projection (MIP) images acquired from dynamic time-resolved MR angiography sequences and compare it with previously described methods.
### Table 1: ISSVA Classification of Vascular Anomalies ©2014

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Methods and materials

We evaluated data for 25 consecutive patients with diagnosed vascular malformations who were examined in our MRI faculty between January 2011 and December 2013. A detailed description of the study group is given in Table 2. On the basis of selective digital subtraction angiography (DSA) examinations and patient clinical data (including color doppler imaging results), malformations were divided into two groups: high flow and low flow.

MR imaging Technique

The MR examinations were performed on a 1.5-T scanner. The study protocol consisted of T₁-weighted, turbo spin-echo (SE) imaging, volume interpolated breath-hold examination (VIBE) with fat saturation, short # inversion recovery (STIR), and contrast-enhanced angiography (time-resolved angiography with interleaved stochastic trajectories; TWIST). T₁-weighted, VIBE, and STIR imaging was performed prior to the administration of contrast agent in two orthogonal planes. TWIST was performed after the administration of contrast agent (0.1 mmol/kg). The injection rate, using a power injector, was 3.5 mL/s and the injection of contrast agent was followed immediately by a 20-mL saline flush administered at the same rate. To obtain delayed venous phase scans, we used 28 consecutive measurements. The temporal resolution, and consequently overall angiography time, depended on the size and location of the lesion and varied between 3 and 4.5 s and between 84 and 126 s, respectively. T₁-weighted imaging and VIBE sequences were repeated after administration of the contrast agent. Two observers independently reviewed the images for each patient. The observers were blinded to the clinical data, as well as to the results of other imaging modalities.

MR Image Analysis

Each malformation was evaluated on the basis of T₁- and T₂-weighted imaging. MIP images generated from the time-resolved MR angiography images were used for further analysis (Fig. 1,2). Each malformation was contoured on the MIP image where it had the largest dimensions. The region of interest (ROI) was copied to all other MIP images and the mean signal intensity was measured. Next, we plotted signal intensity versus scanning time (MIP image number). The signal enhancement curves were analyzed to determine the time of maximum lesion enhancement, the artery-lesion time, and the slope of the enhancement curve in the interval between the beginning of the rise of the curve and its maximum. (Fig. 3). The beginning of arterial enhancement was evaluated in an artery that was not part of the lesion. Thus, the malformations were classified as high-flow or low-flow lesions using the following criteria: (I) findings on T₁- and T₂-weighted imaging
(signal voids, signal intensity); (II) the artery-lesion time; (III) the time of maximum lesion enhancement; and (IV) analysis of the slope of the enhancement curve.

Statistical analysis

Continuous variables are expressed as the median (range). Normality was confirmed or excluded using the Shapiro-Wilk test. Continuous variables were compared using the Mann-Whitney U-test. Statistical significance was set at $P < 0.05$. Receiver operating characteristic (ROC) analysis was used to determine the artery-lesion time, maximum enhancement time, and slope for differentiation of high- and low-flow malformations. In addition, sensitivity and specificity were determined for all methods evaluated.
Table 2: Clinical data for the patient population.

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**Fig. 1:** Maximum intensity projection images of a high-flow malformation.

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Fig. 2: Maximum intensity projection images of a low-flow malformation.

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**Fig. 3:** Enhancement curves and regression lines of high flow (R1) and low flow (R2) malformations. Slope was determined from regression equation: signal intensity = a*time + b; a-slope; b- constant.

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Results

Of the 25 patients for whom data were evaluated, 7 were found to have high-flow malformations and 18 had low-flow malformations. Signal voids on SE T₁-weighted images were observed in only four of seven high-flow malformations (Fig. 4). Signal voids were also observed in two of the 18 low-flow malformations. The sensitivity and specificity of this method to distinguish between high- and low-flow malformations was 57% and 89%, respectively. Analysis of signal intensity on T₂-weighted images showed increased signal intensity in 17 of 18 low-flow malformations, and in two of the high-flow lesions (Fig. 5, 6). The sensitivity and specificity of this method was 71% and 94%, respectively. Calculation of the artery-lesion time, maximum enhancement time, and slope revealed significant differences between the high- and low-flow groups. There was no overlap between the two groups for slope values only (Table 3).

ROC analysis revealed that an artery-lesion time of 4.2 s can be used to distinguish between high-flow and low-flow lesions with 100% sensitivity and 57% specificity. A maximum enhancement time of >27 s can be used as indicator of low-flow malformations, with 94% sensitivity and 100% specificity. Slope values can also be used to classify malformations as high or low flow with 100% specificity and sensitivity. The cut-off value in the case of slope values is 921 s⁻¹ (see Table 4).
**Fig. 4:** T1-weighted turbo spin-echo image of high-flow malformation in the left hand. Arrow shows signal voids in the lesion area.

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Fig. 5: Low-flow malformation of the right thigh. Note no signal voids on the T1-weighted turbo spin-echo image.

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**Fig. 6:** Low-flow malformation of the right thigh. High signal intensity on the T2-weighted turbo spin-echo image.

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<table>
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<tr>
<th></th>
<th>High-flow malformations</th>
<th>Low-flow malformations</th>
<th>n</th>
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<tbody>
<tr>
<td>Artery–lesion time [s]</td>
<td>4.1 (3.1–8)</td>
<td>8.2 (4.2–28)</td>
<td>0.0013</td>
</tr>
<tr>
<td>Enhancement time [s]</td>
<td>17 (14–27)</td>
<td>68 (24–120)</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Slope [s⁻¹]</td>
<td>3168 (1146–4083)</td>
<td>327 (59–921)</td>
<td>&lt;0.0001</td>
</tr>
</tbody>
</table>

**Table 3:** Comparisons between high- and low-flow malformations of the time interval between the start of arterial enhancement and the onset of lesion enhancement (artery-lesion time), the time of maximum lesion enhancement (enhancement time), and the slope of the enhancement curve (slope). Data show median values with the range in parentheses.
Table 4: Results of receiver operating characteristic (ROC) analysis of the time interval between the start of arterial enhancement and the onset of lesion enhancement (artery-lesion time), the time of maximum lesion enhancement (enhancement time), and the slope of the enhancement curve (slope) in distinguishing between high- and low-flow malformations. (AUC - area under the curve)

<table>
<thead>
<tr>
<th></th>
<th>Cut-off value</th>
<th>AUC</th>
<th>Sensitivity [%]</th>
<th>Specificity [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Artery-lesion time [s]</td>
<td>4.2</td>
<td>0.893</td>
<td>100</td>
<td>57</td>
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<tr>
<td>Enhancement time [s]</td>
<td>27.0</td>
<td>0.993</td>
<td>94</td>
<td>100</td>
</tr>
<tr>
<td>Slope [s(^{-1})]</td>
<td>921.0</td>
<td>1.000</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>

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Conclusion

MRI is the established method of choice for the imaging of vascular malformations. In addition to morphological findings on T₁- and T₂-weighted imaging, 3D time-resolved angiography can improve diagnosis. However, the criteria used to classify malformations as high-flow or low-flow lesions vary considerably between studies. In the present study we evaluated previously described methods of classification, as well as a new method based on the slope of the enhancement curve. The results indicate that none of the previously described methods allowed for the discrimination of high-flow from low-flow malformations with 100% specificity and sensitivity.

Determination of the slope of the enhancement curve is a new method for the classification of lesions as high or low flow. In the present study, a slope of $921 \text{ s}^{-1}$ was established as a cut-off point to classify malformations as low-flow lesions.

In conclusion, the slope of the enhancement curve is useful in distinguishing between high- and low-flow vascular malformations. Nevertheless implementation of this method for routine diagnosis requires more research on a larger number of patients.
References


