



Published in final edited form as:

*J Neurosurg.* 2017 February ; 126(2): 495–503. doi:10.3171/2015.11.JNS15562.

## Prior Infarcts, Reactivity, and Angiography in Moyamoya Disease (PIRAMD): A scoring system for moyamoya disease severity based on multi-modal hemodynamic imaging

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### Abstract

**Objective:** Quantification of vasculopathy severity and its impact on parenchymal hemodynamics is a necessary prerequisite for informing management decisions and evaluating intervention response in patients with moyamoya disease (MMD). The authors performed digital subtraction angiography and noninvasive structural and hemodynamic MRI, and they outline a new classification system for patients with moyamoya that they have named Prior Infarcts, Reactivity, and Angi- ography in Moyamoya Disease (PIRAMD).

**Methods:** Healthy control volunteers (n = 11; age 46 +/- 12 years [mean +/- SD]) and patients (n = 25; 42 +/- 13.5 years) with angiographically confirmed moyamoya provided informed consent and underwent structural (T1-weighted, T2- weighted, FLAIR, MR angiography) and hemodynamic (T2\*- and cerebral blood flow-weighted) 3-T MRI. Cerebrovascular reactivity (CVR) in the internal carotid artery territory was assessed using susceptibility-weighted MRI during a hy- percapnic stimulus. Only hemispheres without prior revascularization were assessed. Each hemisphere was considered symptomatic if localizing signs were present on neurological examination and/or there was a history of transient ischemic attack with symptoms referable to that hemisphere. The PIRAMD factor weighting versus symptomatology was optimized using binary logistic regression and receiver operating characteristic curve analysis with bootstrapping. The PIRAMD finding was scored from 0 to 10. For each hemisphere, 1 point was assigned for prior infarct, 3 points for reduced CVR, 3 points for a modified Suzuki Score Grade II, and 3 points for flow impairment in 2 of 7 predefined vascular territories. Hemispheres were divided into 3 severity grades based on total PIRAMD score, as follows: Grade 1, 0–5 points; Grade 2, 6–9 points; and Grade 3, 10 points.

**Results:** In 28 of 46 (60.9%) hemispheres the findings met clinical symptomatic criteria. With decreased CVR, the odds ratio of having a symptomatic hemisphere was 13 (95% CI 1.1–22.6,  $p = 0.002$ ). The area under the curve for individual PIRAMD factors was 0.67–0.72, and for the PIRAMD grade it was 0.845. There were 0/8 (0%), 10/18 (55.6%), and 18/20 (90%) symptomatic PIRAMD Grade 1, 2, and 3 hemispheres, respectively.

**Conclusions:** A scoring system for total impairment is proposed that uses noninvasive MRI parameters. This scoring system correlates with symptomatology and may provide a measure of hemodynamic severity in moyamoya, which could be used for guiding management decisions and evaluating intervention response.

### Keywords

moyamoya; cerebrovascular reactivity; magnetic resonance imaging; hemodynamic; vascular disorders

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### Introduction:

Moyamoya is a progressive steno-occlusive disease of the distal internal carotid arteries (ICA) and their proximal terminal branches. Patients most frequently present with ischemic stroke or recurrent transient ischemic attacks (TIAs). Quantification of vasculopathy severity and its impact on vascular morphology and parenchymal hemodynamics is a necessary prerequisite for informing management decisions and evaluating intervention response. Current management decisions use angiographic data combined with MRI evidence of infarct, along with perfusion studies based on PET or SPECT. Studies of hemodynamic reserve are likely a useful adjunct; however, current clinical methods require exogenous contrast administration and/or ionizing radiation. While such tools have improved our understanding of MMD, these methods are suboptimal for longitudinal monitoring of patients or assessing revascularization response owing to dose restrictions.

Cerebrovascular reactivity (CVR) is a well-documented and valuable surrogate marker of cerebrovascular reserve in patients with previously identified intravascular pathology<sup>1,9,10,12,13</sup>. In healthy parenchyma, CVR primarily derives from a large increase in cerebral blood flow (CBF) and volume (CBV) in response to a vasostimulatory agent such as carbon dioxide (i.e., hypercapnia). Significantly diminished or negative changes in CVR after during hypercapnia have previously been shown to correlate with regions affected by prior infarct and symptomatology<sup>1,26,30</sup>. However, owing to the relative novelty of hypercapnic CVR mapping using MRI compared to more established clinical measures such as acetazolamide SPECT, interpretation of hypercapnic CVR maps has not been standardized.

Here we outline an integrated neuroimaging-based severity classification system for moyamoya titled PIRAMD (Prior Infarcts, Reactivity, and Angiography in Moyamoya Disease). This scoring system accounts for functional measurements of hemodynamic impairment in moyamoya using BOLD MRI-weighted CVR, and therefore may be a comprehensive approach toward stratification of moyamoya severity.

## Methods:

### Patient selection

All procedures were followed in accordance with the ethical standards of the Vanderbilt University Institutional Review Board. Patients presenting with angiographically confirmed moyamoya between January 2011 and May 2015 underwent hemodynamic 3-T MRI (Philips) performed using body coil transmission and 12-channel sensitivity-encoding (SENSE) array neurovascular coil for reception. Patients were included in the study if cerebral digital subtraction angiography (DSA) was performed within 90 days of MRI, without any surgical intervention in the interval. Only hemispheres without a prior revascularization procedure were considered.

### Neurologic assessment

A neurologist (L.J.) retrospectively reviewed patient symptomatology derived from the electronic medical record. Symptomatic hemispheres were defined as those with either a history of recurrent localizable transient ischemic attacks or persistent neurological deficits (motor, sensory, and/or language) referable to the hemisphere. Psychological symptoms, deficits in concentration and memory, and/or headache were not included, given the potential ambiguity in localization

### Imaging Protocol

BOLD imaging consisted of a T2\*-weighted single-shot GRE Echo Planar Imaging (EPI) acquisition (slice thickness=5 mm, TR/TE=2000/35ms, FOV = 240×240 mm, spatial resolution=3×3×5 mm) across the entire brain. The experimental paradigm consisted of 5 total blocks each of 3 minutes duration, beginning and ending with the delivery of medical grade room air and interleaved with hypercapnic gas (5% CO<sub>2</sub> / 95% O<sub>2</sub>) administration. We have recently quantified relationships between such hypercarbic hyperoxic and hypercarbic normoxic stimuli in healthy adults and patients with intracranial stenosis<sup>9</sup> and have demonstrated abilities for this stimulus to be performed safely in a large volume of patients, provide contrast consistent with symptomatology and lateralizing disease, and correlate with perfusion reactivity upon appropriate post-processing. Gas delivery was performed using a custom non-rebreathing facemask, and core physiologic parameters including end tidal CO<sub>2</sub> (EtCO<sub>2</sub>), heart rate, blood pressure, and arterial oxygen saturation were monitored throughout the experiment.

### Radiologic Evaluation

**Prior Infarct:** Each hemisphere under review was considered separately. Two board-certified neuroradiologists (M.K.S., T.L.D.) blinded to clinical status and hemodynamic findings reviewed FLAIR imaging acquired at the time of BOLD MRI to determine presence of infarct. T2-weighted imaging was also reviewed when available. For lacunar infarcts, a size criterion for T2 hyperintense lesions of greatest axial diameter > 4 mm was used to separate prior infarcts from white matter changes<sup>17,23</sup>. The T1-weighted sequence was used to verify encephalomalacia when infarcts were suspected based on the FLAIR sequence.

**Cerebrovascular Reactivity:** Healthy controls (n=11; 46±3.5yrs) and patients (n=23; age=41.0±3.0yrs) provided written informed consent and underwent structural (T1w, T2w, FLAIR, MRA) and hemodynamic (T2\* and CBF-weighted) 3T MRI (Figure 1). The ICA territory was defined by a pre-determined mask (Figure 2) ICA-territory CVR was assessed using susceptibility-weighted MRI during a hypercapnic ( EtCO<sub>2</sub> ~5mmHg; repeats=2) stimulus and normalized to cerebellar CVR. For each patient hemisphere (anterior circulation), the number of standard deviations by which CVR differed from the control mean CVR (Z-statistics: mean=0.69; SD=0.19) was calculated.

**Digital Subtraction Angiography:** Moyamoya changes on DSA were scored with a modified Suzuki Score (mSS), ranging from 0 to IV by two neuroradiologists (Table 1) with higher grades representing more severe disease.<sup>31</sup> The mSS accounts for internal carotid, middle cerebral artery, and anterior cerebral artery disease, along with presence or absence of lenticulostriate collaterals. Regional collateralization on DSA was assessed via modification of a previously reported technique<sup>19,33</sup> In brief, DSA was divided into 7 anatomic sites based on ASPECTS-defined regional vascular territories<sup>29,33</sup>: M1-M6 and basal ganglia (Figure 3). An interventional neurologist (M.F.) and a neuroradiologist (M.S.) working in tandem reviewed each territory on DSA for each patient and assessed whether regional blood flow was impaired or not for the ASPECTS-defined regions. A territory was considered impaired if there were no visible collaterals supplying the ischemic site or there were collaterals only to the periphery of the ischemic site. A territory was considered not impaired if collateral flow provided complete irrigation of the ischemic bed or if there was normal anterograde flow. Flow classification was made based on consensus. The total number of impaired territories (0–7) was counted for each hemisphere.

### PIRAMD Optimization and Analysis

Each component of PIRAMD was converted to a categorical variable and given a preliminary, simplified scoring system. The preliminary scoring system was optimized via simple logistic regression analysis and receiver operating characteristic (ROC) curve analysis using symptomatology as the dependent variable to determine a clinically valid and statistically significant stratification system. Acceptability criteria were p<0.05 for binary logistic regression analysis and area under the curve (AUC) >0.6 for ROC curve analysis. PIRAMD component grading is summarized in Table 2.

### PIRAMD Grading

The relative weight for each factor in the PIRAMD score was determined by using the factor's odds ratio from simple logistic regression analysis. The lowest odds ratio was used as the baseline by which all other factors were scaled. The weighted scores for each component of PIRAMD were added together for a raw PIRAMD score. PIRAMD score was divided into three grades: PIRAMD 1, PIRAMD 2, and PIRAMD 3. Grade stratification was determined through optimization by ROC curve analysis and simple binary logistic regression analysis, considering PIRAMD score as a discrete independent variable for those purposes. ROC and binary logistic regression analyses were also repeated for PIRAMD grade. Acceptability criteria were p<0.01 for binary logistic regression analysis and area under the curve (AUC) >0.8 for ROC curve analysis.

## PIRAMD Validation

Additional internal validation was conducted on the dataset via a bootstrap method. 95% confidence interval estimates for the binary logistic regression analyses were generated in SPSS using a bootstrap sample size of 1,000. Bootstrapped p values and confidence intervals were obtained and reported. ROC bootstrapping also was performed in SPSS using an adapted public domain macro (Available: <http://gjyp.nl/marta/>), with a bootstrap sample size of 1,000. Bootstrapped AUC and 95% confidence intervals were obtained and reported.

## Results

### Participants in Study

There were 25 moyamoya participants in the study, accounting for 46 hemispheres (Table 3). The mean age was 42 years, with a SD of 12 years. Most patients were female (20, 80%). There were 28 (60.9%) symptomatic hemispheres. The majority of patients had bilateral disease (22, 88%). Four of the 46 hemispheres analyzed (8.7%) had a prior contralateral revascularization surgery, but none had a prior ipsilateral revascularization surgery. The mean interval between MRI scan and diagnostic angiography was 30 days with a SD of 24.2 days.

### Structural MRI Data

Thirty (65.2%) hemispheres had a prior infarct on T2-weighted FLAIR imaging. With a prior infarct, the odds of having a symptomatic hemisphere were 4.6 times greater than without a prior infarct; however, the bootstrapped confidence interval estimates crossed unity and were not statistically significant (95% CI: 0.3–3.3,  $p=0.016$ , Table 4). AUC for prior infarct was 0.670 (95% CI: 0.539 – 0.802).

### Hemodynamic MRI Data

After normalizing ICA territory CVR by total cerebellar CVR, 35 (76.1%) patients had reduced normalized CVR relative to the control cohort. With CVR lower than control CVR, the odds of having a symptomatic hemisphere were 13 times greater than when normal or increased CVR was present (95% CI: 1.1–22.6,  $p=0.002$ ). AUC for CVR was 0.716 (95% CI: 0.585 – 0.844).

### Angiographic Data

Thirty-eight (82.6%) hemispheres were mSS of Grade II or greater. With a mSS in this range, the odds of having a symptomatic hemisphere were 17.2 times greater than Grade 0–1 mSS (95% CI: 1.1–22.7,  $p=0.008$ ). AUC for mSS was 0.678 (95% CI: 0.560 – 0.793).

With regard to collateral flow impairment, 35 (76.1%) hemispheres had 2–7 territories impaired; With 2–7 impaired territories, the odds of having a symptomatic hemisphere were 13 times greater than 0–1 territories impaired (95% CI: 1.1–22.7,  $p=0.006$ ). AUC for mSS was 0.713 (95% CI: 0.593 – 0.836).

## Development of PIRAMD Score

Following the simple analysis of the individual PIRAMD factors, the relative weighting for each factor was determined by scaling the odds ratio for prior infarct (4.6), as this had the lowest odds ratio. The PIRAMD scoring system is summarized in Table 2. Scores were added to achieve the hemisphere's PIRAMD score, and in this way, PIRAMD was scored from 0 to 10, with increasing score representing increasing impairment (Figure 4).

## PIRAMD Grade

Hemispheres were divided into three severity grades based on total PIRAMD score: Grade 1: 1–5 points; Grade 2: 6–9 points; and Grade 3: 10 points. There were 0/8 (0%), 8/18 (55.6%), and 18/20 (90%) symptomatic PIRAMD 1, 2, and 3 hemispheres, respectively (Figure 5). AUC for PIRAMD grade (1–3) was 0.845 (95% CI: 0.735 – 0.956). AUC for PIRAMD score was 0.860 (95% CI: 0.746–0.974).

## Discussion

PIRAMD is a simple scoring system for total impairment in MMD, which utilizes non-invasive functional MRI parameters in addition to angiography. PIRAMD was found to correlate well with symptomatology (AUC=0.860). There were 0/8 (0%), 8/18 (55.6%), and 18/20 (90%) symptomatic PIRAMD 1, 2, and 3 hemispheres, respectively.

Patients with MMD are heterogeneous with regard to their clinical presentations and outcomes; however angiographic studies alone may not be sufficient to understand patient pathophysiology. Clinical severity does not follow a perfect correlation with angiography, as proximal occlusions may be completely compensated by robust pial and lenticulostriate auto-collateralization. In contrast, uncompensated mild stenosis may portend a severe course<sup>21,31</sup>. In some cases, angiography may not even correlate with hemodynamic impairment<sup>4</sup>.

As surgical candidacy is weighed heavily by imaging appearance and symptomatology, efforts to stratify patients for intervention are critical. A contemporary issue in the management of patients with MMD is the selection of impaired individuals who are likely to benefit from surgical revascularization. CVR may be predictive of outcome, and may be useful in noninvasive monitoring of such patients<sup>15,20,24,28</sup>. Han et al. have shown that post-revascularization CVR correlated with graft patency and clinical outcomes in MMD<sup>15</sup>. In intracranial stenosis in general, Mandell showed that patients with impaired CVR were more likely to have hemodynamic normalization post-revascularization<sup>25</sup>.

There has been a robust effort in the field to quantify and understand hemodynamic impairment in MMD. CVF and CBV increase in the early stages of impairment, and oxygen extraction fraction (OEF) increases when CBF cannot increase sufficiently to meet oxygen demands<sup>22</sup>. The current methods available for assessing these impairments include PET, SPECT, Xenon-CT, dynamic perfusion CT, DSC-MRI, ASL-MRI, and Doppler ultrasound (see Table 1 in Lee et al.<sup>22</sup>). However, many of these methods (e.g. PET, SPECT, Xenon-CT, and dynamic perfusion CT) require ionizing radiation exposure and/or administration of exogenous contrast (e.g. gadolinium, which causes renal failure in up to 2% of cases<sup>3</sup>).



Diagnostic angiography carries risk, with a complication rate as high as 1.2% in the Asymptomatic Carotid Atherosclerosis Study<sup>11</sup>, in addition to potential dose-dependent radiation-induced skin injuries<sup>32</sup>.

MRI uses blood oxygenation level as an endogenous contrast agent, and therefore does not require exogenous contrast or ionizing radiation. It can be acquired serially during routine structural MRI for patients, and therefore holds promise as a noninvasive, readily available, and valid adjunct to routine imaging of MMD patients. Additionally, MR offers improved spatial (3–5 mm isotropic) and temporal (2–3s) resolution and may be more clinically available compared to PET and SPECT, especially in non-specialized hospitals.

In patients with intracranial disease, secondary reductions in cerebral perfusion pressure may initially be compensated for via an increase in cerebral blood volume (CBV) and CBF<sup>2,7</sup>. To assess this autoregulatory capacity, a vasostimulus such as carbogen can be administered. Carbogen serves to increase the arterial partial pressure of O<sub>2</sub> and CO<sub>2</sub>, CBF, and CBV, and in turn increases blood oxygenation. The resulting increase in the ratio of oxyhemoglobin compared to deoxyhemoglobin will lead to an increase in T2\*-weighted MRI signal. The magnitude of this change in the BOLD signal, or CVR, reflects the ability of vessels to regulate CBF and CBV, indicating how close parenchyma is to failing to meet the hemodynamic demand. This permits an endogenous signal to be measured rather than having to rely upon exogenous contrasts or acetazolamide. Carbogen is a safe substance for CVR measurement; in our experience with 92 consecutive patients, carbogen elicited no short-term neurological events, and longer term (2-year) events fell within the expected range for patients with intracranial stenosis<sup>9</sup>.

Although the role of CVR in predicting long-term stroke risk is not yet completely known, numerous studies have established a strong correlation between CVR and intracranial vascular disease<sup>9,16</sup>. In patients with moyamoya, strong inverse relationships between mean CVR and both Suzuki score and the presence of collateral vessels have been identified<sup>4,18</sup>. Moyamoya patients refractory to medical management undergoing surgical revascularization have been shown to demonstrate post-surgical revascularization improvements in CVR in regions which were previously compromised<sup>15,25,27</sup>.

Using Xenon-CT with acetazolamide challenge in 40 patients (80 hemispheres), Czabanka et al. created a similar scoring mechanism for MMD severity<sup>6</sup>. Compromised cerebrovascular reserve capacity was defined with Xenon-CT as CBF decreased by greater than 5% after acetazolamide challenge. Although for methodological reasons we were unable to compare PIRAMD to the Czabanka system directly, the AUC was similar between populations (0.80 vs. 0.86). While that study has laid the foundation for using CVR in moyamoya severity stratification, the technical innovations that have occurred since then have lead us to conclude that PIRAMD might be a more favorable scoring system for patients, particularly in the United States, where there is not widespread xenon use due to concerns in the literature and from the FDA related to reports of respiratory side effects with xenon.<sup>5</sup> Symptomatic classification was more conservative in our study. Whereas Czabanka et al. considered psychological or headache symptoms as bilaterally symptomatic, these were not counted in our study for difficulty in localization. This may account for the

apparent difference in prevalence of symptomatic hemispheres between cohorts (61% in our study, 68% in the study by Czabanka et al.).

We find it interesting that a milder correlation with symptomatology in our study was found with prior infarct. This is not to say that prior infarct is not important, as it indicates that significant hemodynamic impairment has already occurred. In fact, we found post-hoc that 22/28 (78.6%) of symptomatic hemispheres had an infarct. There was, however, a high rate of clinically silent infarcts (8/30 infarct, 26.7%), particularly in the watershed distribution. There was considerable collinearity with other PIRAMD components; if a prior infarct was present, in all but two cases (93.3%), impairment in another PIRAMD component was also present. Unsurprisingly, with prior infarct the mean PIRAMD score was 8.5 versus 6.2 without ( $p=0.013$ ). However, for the hemispheres without infarct (especially the 21% of symptomatic hemispheres without infarct), the PIRAMD score adds more clarity to hemodynamic impairment than just infarct assessment alone. Patients without infarct may have other impairments that increase the PIRAMD score, and this may weigh more heavily on the decision to revascularize.

Therefore, it is useful to complement this information with functional measures of impairment. The angiographic assessment of collateral perfusion is a strong contributor to PIRAMD score, as it allows a functional, dynamic assessment of territory perfusion. However, it is invasive and requires radiation, which may limit its use in serial monitoring. Thus, we offer a functional complement of parenchymal impairment via BOLD MRI<sup>8</sup>. The measurement of CVR using MRI provides a noninvasive method for assessing hemodynamic instability. We found that reduced CVR carried a 13-fold increase in odds of being symptomatic. When synthesizing angiographic, structural, and hemodynamic MRI evidence of impairment via the PIRAMD score, the probability of being symptomatic can be calculated. We found that hemispheres were asymptomatic until PIRAMD score reached 6, at which a precipitous proportional rise in symptomatology occurred (Figure 4).

The PIRAMD severity grades may be useful in counseling patients for further management. In particular, PIRAMD 3 patients, if not already symptomatic, might have a high risk of becoming symptomatic, and surgery should be more strongly considered. In contrast, PIRAMD 1 patients might not become symptomatic, and conservative management with serial monitoring may be recommended. Of course, while reduced CVR may be associated with greater stroke risk<sup>14</sup>, the long-term risks of PIRAMD grades have not yet been evaluated, and would need to be assessed in larger prospective studies. Nonetheless, the strong correlation between PIRAMD score and symptomatology suggests it may still have a role in patient stratification.

## Limitations

This study is limited by its retrospective nature and small sample size, necessitating univariate analysis. While we included patients if DSA was performed within 90 days, it would have been more ideal to have these studies obtained concurrently; the mean interval between angiography and MRI was 30 days. Though we performed a limited internal validation via bootstrapping, external validation with a larger number of patients is needed.



This study addresses historic symptom risk, and does not predict future symptoms or postoperative response, and therefore we are continuing to evaluate this prospectively.

## Conclusion

A scoring system for total impairment in moyamoya is proposed which utilizes non-invasive MRI parameters along with conventional angiography. This scoring system was found to correlate with symptomatology and may provide an objective measure of hemodynamic severity in moyamoya, which could be used for guiding management decisions and evaluating intervention response.

## Acknowledgments:

None

Disclosure:

This work was supported by the National Institutes of Health (5R01NS078828–02). T.R.L. received funding via the Medical Student Summer Research Fellowship from the American Association of Neurological Surgeons. A portion of the findings were presented as an oral abstract at the 2015 AANS/CNS Joint Cerebrovascular Section Annual Meeting on February 9<sup>th</sup>, 2015 in Nashville, TN.

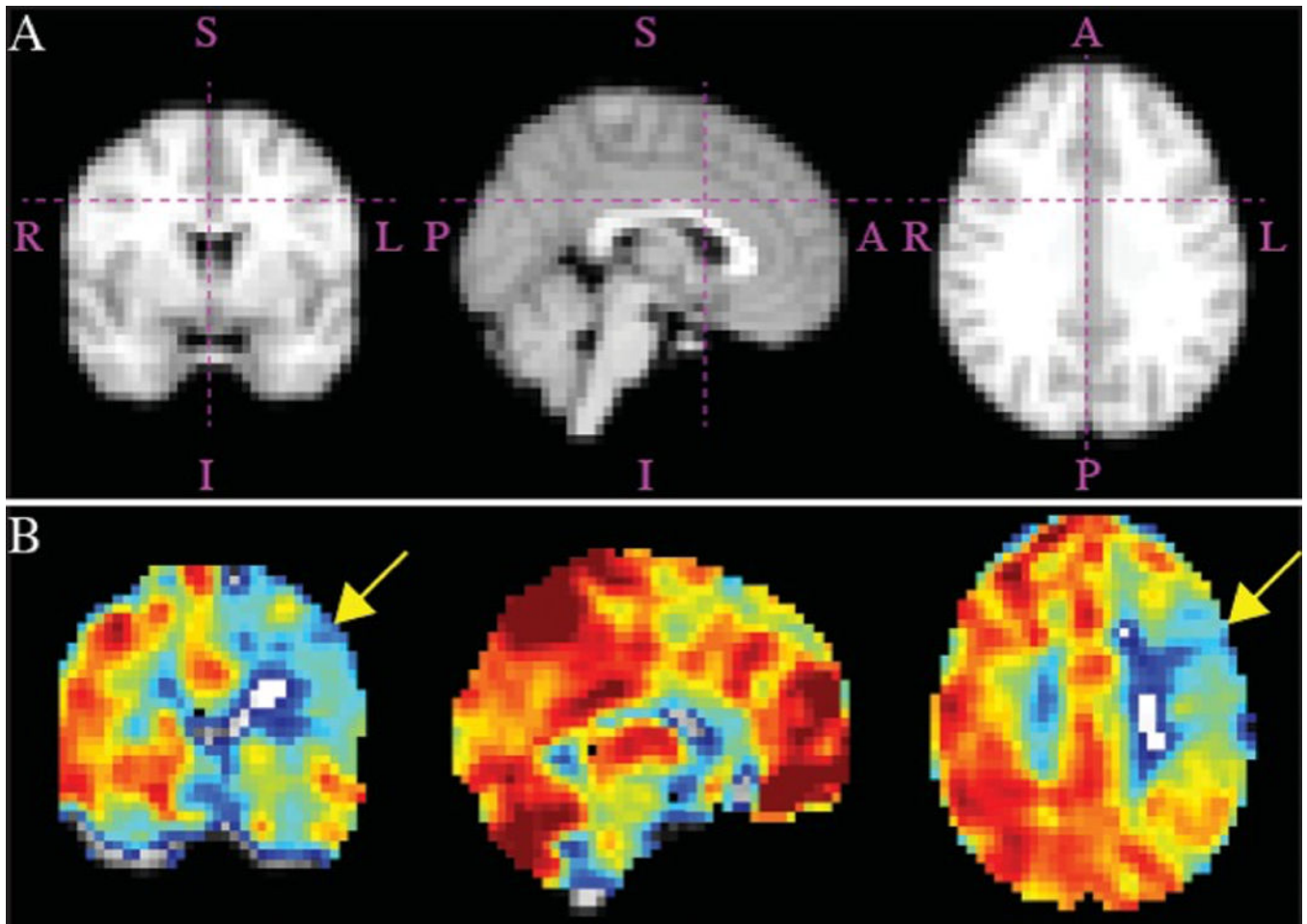
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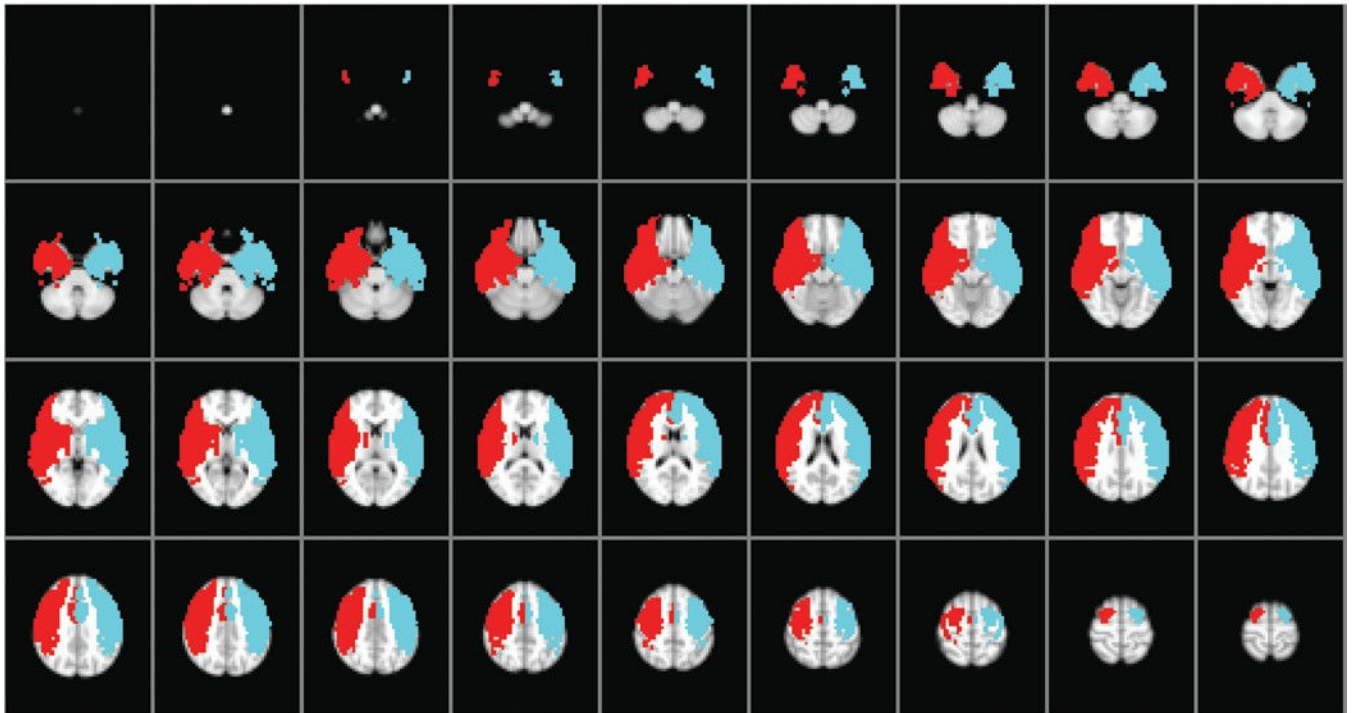
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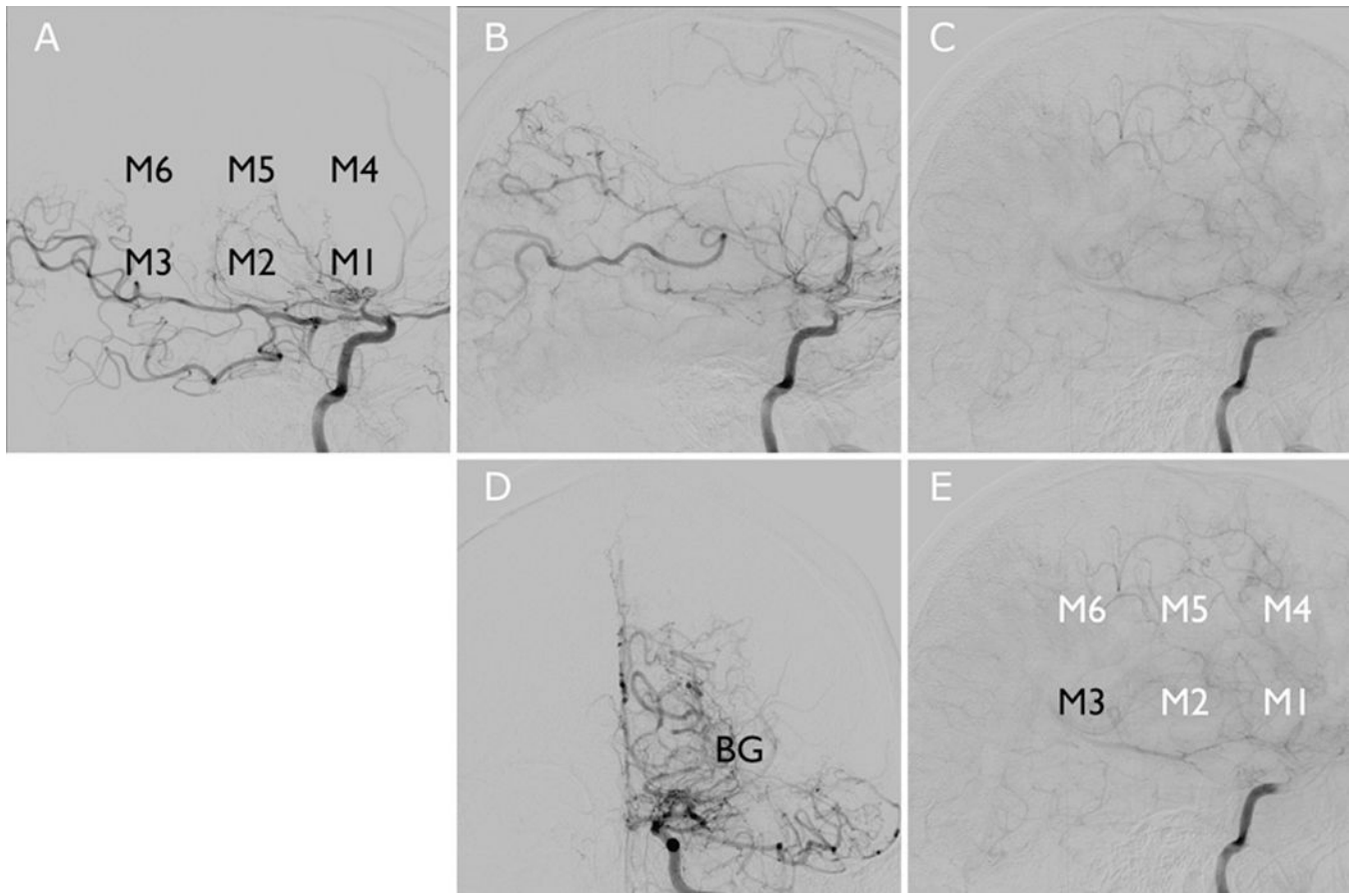
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**Figure 1.** Admission MRI studies obtained in a patient with a symptomatic left hemisphere. Corresponding atlas maps for hemodynamic sections (a) and orthogonal representations of reactivity maps (b), demonstrating impairment in CVR in the left hemisphere (yellow arrows). Right hemisphere (asymptomatic) PIRAMD score: 0 (Grade 1); left hemisphere (symptomatic) PIRAMD score: 10 (Grade 3). A = anterior; I = inferior; L = left; P = posterior; R = right; S = superior. Figure is available in color online only.

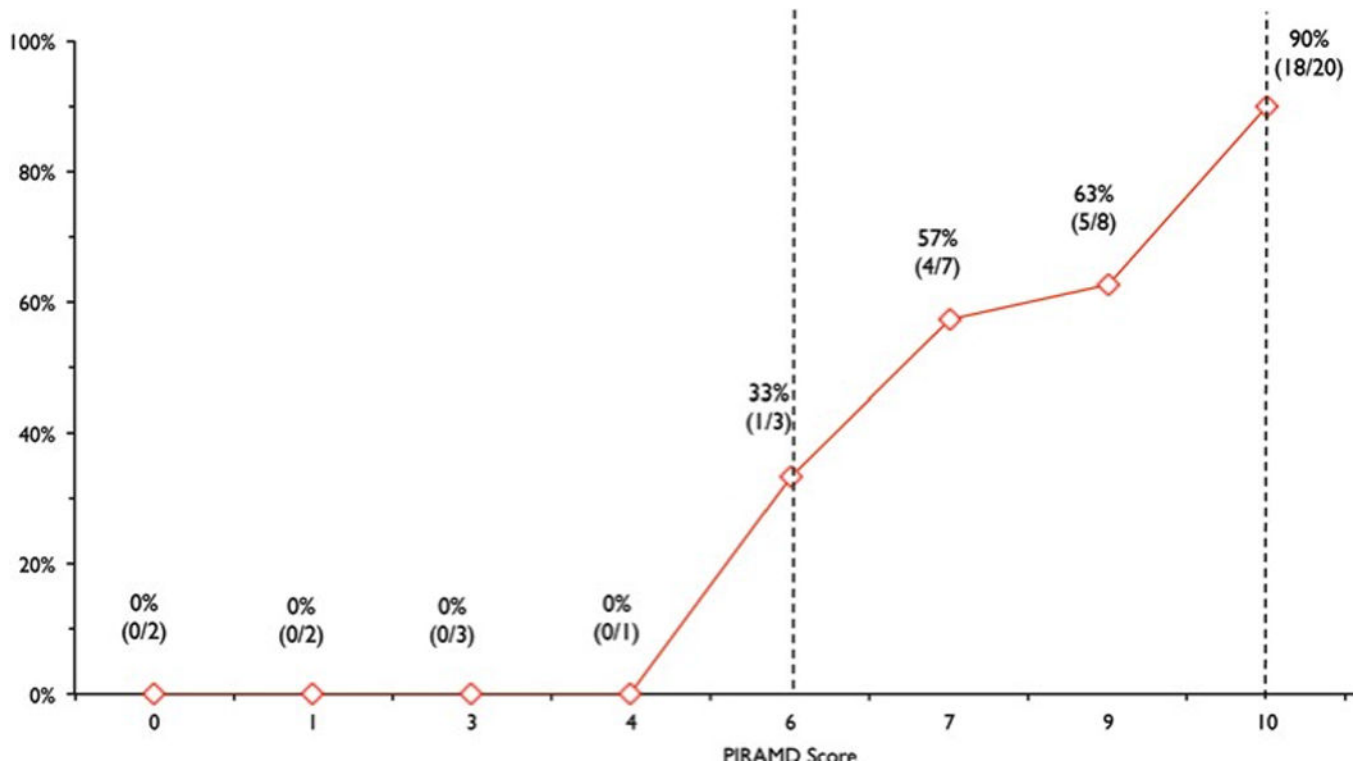


**Figure 2.**  
The ICA territory masks used to define right (red) and left (blue) regions of interest for assessment of CVR. Figure is available in color online only.

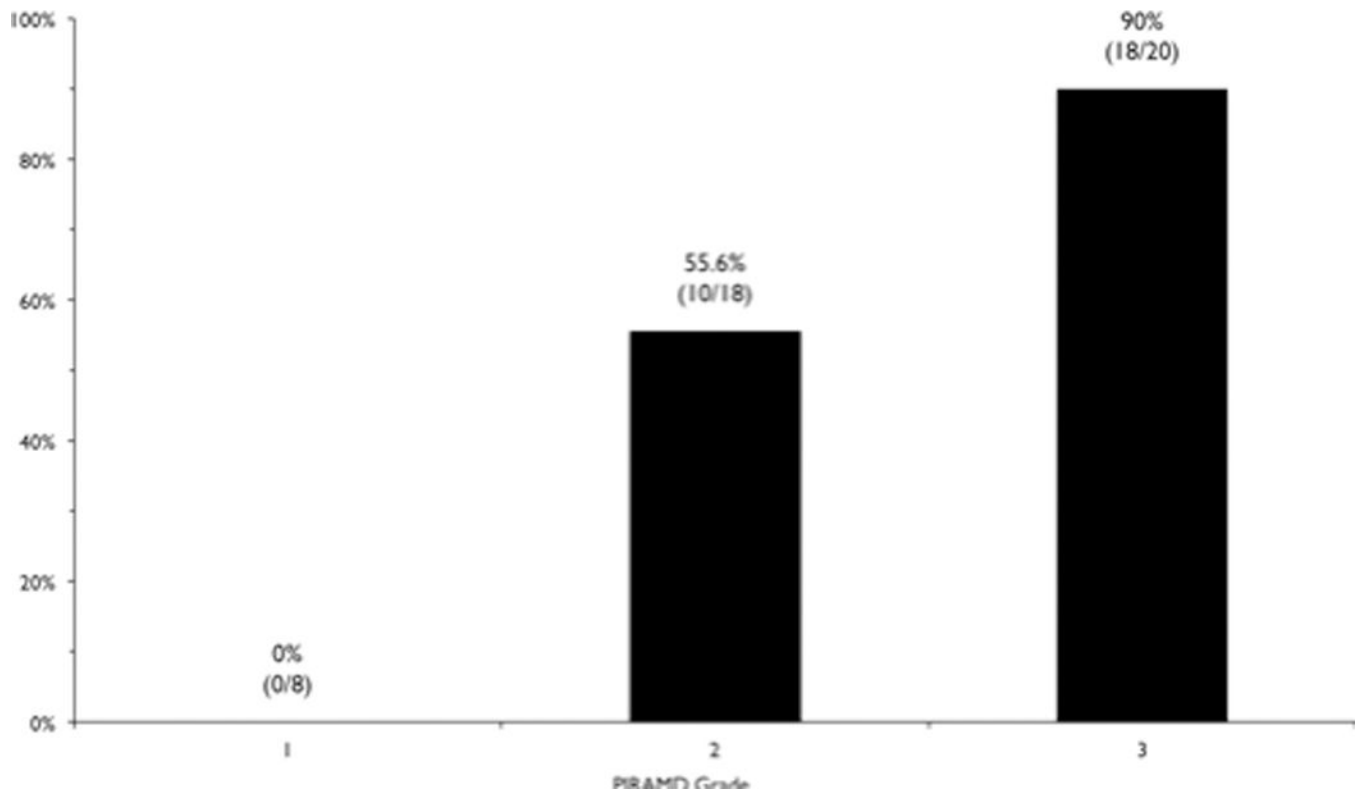


**Figure 3.** Lateral projections (a, early-; b, mid-; and c, delayed-phase sequences) from left ICA injection on DSA. The 7 DSA territories measured are labeled in the lower row from the same left ICA injection (D, AP projection; e, lateral projection); impaired regions with delayed perfusion from collaterals are labeled in white (E). BG = basal ganglia; M1–M6 = ASPECTS territories.





**Figure 4.** Graph showing the PIRAMD grade versus proportion of patients who were symptomatic. Vertical dashed lines represent PIRAMD Grade 2 (6) and Grade 3 (10) demarcations, respectively. Figure is available in color online only.



**Figure 5.** Bar graph showing the PIRAMD grade versus symptomatology. There were 0/8 (0%), 10/18 (55.6%), and 18/20 (90%) symptomatic PIRAMD Grade 1, 2, and 3 hemispheres, respectively.

**Table 1:**

## Modified Suzuki Score \*

Score	Description of classification
0	No evidence of disease
I	Mild-to-moderate stenosis around ICA bifurcation with absent or slightly developed ICA MMD
II	Severe stenosis around the ICA bifurcation or occlusion of either proximal anterior or MCA branches with well-developed ICA MMD
III	Occlusion of both anterior 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)
IV	Complete occlusion of both anterior and MCA branches with absent or small amount of ICA MMD (without opacification of either anterior or MCA branches in antegrade fashion)

MMD = moyamoya disease.

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**Table 2:**

## The PiramMD Scoring system

Variable	Characteristics	Points
MRI	Prior infarct	1.0
CVR	Decreased	3.0
mSS	Grade II	3.0
Collaterals	2 territories impaired	3.0

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**Table 3:**

Characteristics of patients and hemispheres in study

	Characteristic	Value
<b>By patient (n=25)</b>		
<i>Demographic data</i>		
	Age in yrs, mean $\pm$ SD	42 $\pm$ 13.5
	Female sex	20 (80%)
	Race:	
	Asian/Pacific Islander	3 (12%)
	Black/African American	8 (12%)
	White/Caucasian, Hispanic/Latino	1 (4%)
	White/Caucasian, non-Hispanic/Latino	13 (52%)
<i>Clinical data</i>		
	Bilateral moyamoya	22 (88%)
	Days between MRI and DSA, mean $\pm$ SD	30 $\pm$ 24.2
<b>By hemisphere (n=46)</b>		
<i>Clinical data</i>		
	Symptomatic	28 (60.9%)
	Prior contralateral revascularization	4 (8.7%)
	Infarct:	
	No prior infarct	16 (34.8%)
	Prior infarct	30 (65.2%)
	CVR:	
	Normal/increased	11 (23.9%)
	Decreased	35 (76.1%)
	mSS:	
	0	3 (6.5%)
	I	5 (10.9%)
	II	20 (43.5%)
	III	14 (30.4%)
	IV	4 (8.7%)
	Number of collaterals impaired:	
	0	10 (21.7%)
	1	1 (2.2%)
	2	6 (13.0%)
	3	10 (21.7%)
	4	10 (21.7%)
	5	3 (6.5%)
	6	3 (6.5%)
	7	3 (6.5%)

	Characteristic	Value
<b>By patient (n=25)</b>		
<i>Demographic data</i>		
	PIRAMD grade	
	1	8 (17.4%)
	2	18 (39.1%)
	3	20 (43.5%)

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**Table 4:**

Correlations with symptomatology

Component	AUC	95% CI	Subscore	OR	95% CI	p-Value
Prior Infarct	0.670	0.539–0.802	Present	4.6	0.3–3.3	0.016
CVR	0.716	0.585–0.844	Decreased	13.0	1.1–22.6	0.002
mSS	0.678	0.560–0.793	Grade II	17.2	1.1–22.7	0.008
Collaterals	0.713	0.593–0.836	2 Territories	13.0	1.1–22.7	0.006
PIRAMD Grade	0.845	0.735–0.956	2	NA	20.4–22.5	0.004
			3	NA	22.3–42.4	0.004

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