J Neurol (2013) 260:21–29
DOI 10.1007/s00415-012-6576-5

ORIGINAL COMMUNICATION

Prevalence, timing, risk factors, and mechanisms of anterior cerebral artery infarctions following subarachnoid hemorrhage

Michael Moussouttas · Torrey Boland · Lily Chang · Ameesh Patel · Jaime McCourt · Mitchell Maltenfort

Received: 30 November 2011 / Revised: 25 May 2012 / Accepted: 31 May 2012 / Published online: 24 June 2012

Abstract Anterior cerebral artery (ACA) ischemia may be underdiagnosed following subarachnoid hemorrhage (SAH). The purpose of this study is to characterize the prevalence, timing, and risk factors for ACA infarction, following primary spontaneous SAH. This was a retrospective study of consecutive SAH patients. Final admission CT scans were reviewed for the presence of ACA infarction, and prior scans serially reviewed to determine timing of infarct. Infarctions were categorized as any, early (days 0–3), late (days 4–15), or perioperative (2 days after aneurysm treatment). Demographic and clinical variables were statistically interrogated to identify predictors of infarct types. Of the 474 study patients, ACA infarctions occurred in 8 % of patients, with 42 % occurring during the early period. Multivariate logistic regression identified H/H grade 4/5 ($p < 0.001$), ACA/ACom aneurysm location ($p < 0.001$), and surgical clipping ($p = 0.011$) as independent predictors of any ACA infarct. In Cox hazards analysis, H/H grade 4/5 ($p < 0.001$), CT score 3/4 ($p = 0.042$), ACA/ACom aneurysm location ($p < 0.001$), and surgical clipping ($p = 0.012$) independently predicted any ACA infarct. Bivariate logistic regression identified non-Caucasian race ($p = 0.032$), H/H grade 3/4 ($p < 0.001$), CT score 3/4 ($p = 0.006$), IVH ($p = 0.027$), and ACA/ACom aneurysm ($p = 0.001$) as predictors of early infarct (EI). Late infarct (LI) was predicted by H/H grade 4/5 ($p = 0.040$), ACA/ACom aneurysm ($p < 0.001$), and vasospasm ($p = 0.027$), while postoperative infarct (PI) was predicted by surgical clipping ($p = 0.044$). Log-rank analyses confirmed non-Caucasian race ($p = 0.024$), H/H grade 3/4 ($p < 0.001$), CT score 3/4 ($p = 0.003$), IVH ($p = 0.010$), and ACA/ACom aneurysm ($p < 0.001$) as predictors of EI. LI was predicted by ACA/ACom aneurysm ($p < 0.001$) while surgical clipping ($p = 0.046$) again predicted PI. Clinical severity/grade and ACA/ACom aneurysm location are the most consistent predictors of ACA infarctions. Vasospastic and non-vasospastic processes may concurrently contribute to ACA infarcts.

Keywords Subarachnoid hemorrhage · Anterior cerebral artery · Infarction · Prevalence · Timing · Risk factors

M. Moussouttas (✉)
Cerebrovascular and Critical Care Division, Department of Neurology, Thomas Jefferson University Medical Center, 900 Walnut Street, Suite 200, Philadelphia, PA 19107, USA
e-mail: arista1@pol.net

T. Boland
Department of Neurology, Thomas Jefferson University Medical Center, Philadelphia, USA

L. Chang · A. Patel · J. McCourt
Thomas Jefferson University Medical Center, Philadelphia, USA

M. Maltenfort
Department of Neurosurgery, Thomas Jefferson University Medical Center, Philadelphia, USA

Introduction

Subarachnoid hemorrhage (SAH) represents 5 % of all cerebrovascular events, and is associated with an approximately 30 % mortality rate and 20 % disability rate [1]. Among the various complications of SAH, cerebral infarction represents a major determinant of outcome [2, 3], and clinical or radiologic vasospasm represent major predictors of infarction [4]. However, it has recently been

proposed that cerebral infarction in SAH may also occur independent of vasospasm [5].

Compared to the MCA territory, ACA ischemia may be less likely to present with major visual, sensory, motor, or language/spatial deficits, and may be difficult to identify on compromised patients in the intensive care unit [4, 6]. Similarly, transcranial ultrasound (TCUS) is accurate in identifying MCA vasospasm, but limited in detecting anterior cerebral artery (ACA) spasm [7]. Thus, ACA spasm and ischemia may frequently remain undiagnosed and untreated.

The purpose of this study is to characterize the prevalence, timing, risk factors, and possible mechanisms of ACA infarctions in patients with primary spontaneous SAH, in the early acute and late subacute periods.

Methods

Study overview, patient selection, data acquisition

The study is a retrospective analysis of a prospectively compiled database for consecutively admitted primary spontaneous non-recurrent SAH patients admitted to the Jefferson Hospital for Neurosciences between March 21, 2008 and July 30, 2010. Patients with SAH due to trauma, arteriovenous malformation, or intracerebral hemorrhage were excluded, as were patients without any cerebral imaging. Data collection included demographic characteristics (age, gender, race), medical history (hypertension, tobacco use), clinical presentation (H/H grade), radiologic information (CT scans and transcranial ultrasound), anatomic aspects (aneurysm location), and treatment modalities (clipping vs. coiling).

Standard treatment protocols

Upon admission to the neurological intensive care unit, all SAH patients typically receive maintenance normal saline at a rate of 60–80 ml/h, and receive no enteral nutrition in anticipation of angiography and aneurysm treatment. Agitated patients are given sedation (propofol or midazolam or fentanyl), mean arterial pressures (MAP) are maintained below 90 mmHg, and stuporous patients are routinely intubated and ventilated. No patients receive antifibrinolytic agents, ventriculostomies are inserted for relief of hydrocephalus, prophylactic antiepileptic medication is administered, and patients are started on nimodipine. Following aneurysm treatment, sedating medications are discontinued, MAPs are maintained between 90 and 100 mmHg, patients are extubated or gradually tapered from ventilator support, intravenous fluids are continued to maintain euvolemia, and enteral nutrition is initiated. Hyponatremia is treated by oral sodium chloride 3 g three times daily, and by hypertonic saline if/when levels are below 120 mEq/l. Any neurological worsening at any time is evaluated by head CT.

All patients routinely undergo TCUS monitoring twice daily for the detection of vasospasm. Vasospasm at our neurosonology center is defined as MCA velocities >120 cm/s with ipsilateral MCA/ICA ratios >3, ACA velocities >100 cm/s (possible) or >120 cm/s (probable) or >150 cm/s (definite), BA velocities >80 cm/s with BA/Vamean ratios >2, and VA velocities >60 cm/s. Upon development of sonographic vasospasm, MAP parameters are raised to between 100 and 110 mmHg, and for symptomatic vasospasm MAP parameters may reach 110–120 mmHg. Vasospasm refractory to hypertensive therapy may be treated by endovascular injection of nicardipine, and possibly angioplasty at the discretion of the interventionalist neurosurgeon.

Determination and timing of infarction

ACA infarction was defined as any acute ACA territory infarction evident on cerebral CT scan that occurred at the time of ictus or any time during hospitalization. To determine the presence or absence of ACA infarction, the last head CT done from admission was evaluated for any recent ACA territorial infarction. To determine the timing of infarction, all prior CT scans were reviewed serially in retrospective fashion. The first CT to reveal infarction, and the last CT without infarction, were used as index images to determine the day of infarct onset. If necessary, lesion density was assessed to determine stage of infarct evolution, and imaging reviewed to estimate approximate age of infarction. All scans were interpreted by certified neuroradiologists and cerebrovascular specialists, and infarctions were identified (or excluded) based upon expert consensus opinion.

Infarct characterization and categorization

ACA infarcts occurring between day 0 (day of onset) and day 3 were considered early infarcts (EIs), whereas those occurring between day 4 and 15 were considered late infarcts (LIs). Timing of surgical (clip) or interventional (coil) aneurysm treatment from the time of hemorrhage onset was documented, as was the timing of infarction relative to the time of treatment. Infarctions were considered postoperative (PI) if they occurred within 48 h after treatment for an ACA or an anterior communicating artery (ACom) aneurysm. Infarct categorization as early or late did not preclude co-categorization as postoperative. Infarctions whose day of onset was impossible to determine

based on available imaging studies were considered "indeterminate".

Definitions and data grouping

Race was defined as being Caucasian, African, Hispanic, or Asian. Clinical condition was graded using the Hunt-Hess (H/H) scale, and CT scans were scored according to the system by Frontera et al. [8], which provides the most linear correlation between amount of hemorrhage and risk for vasospasm and adverse outcomes. For the categories of H/H grade and CT score, data was dichotomized into grades 1–3 versus 4/5, and scores 0–2 versus 3/4, respectively. Treatment was divided between surgical clipping (or wrapping) versus endovascular coiling (±stenting). Aneurysm location was determined by review of all angiograms. If multiple aneurysms were present, review of CT scans and adjudication to determine the most likely site of rupture was performed. If adjudication was inconclusive, all aneurysm locations were listed. Mean maximum ACA velocities on TCUS, and the proportion of patients achieving various levels of velocity elevations considered to potentially represent vasospasm, were compared between infarction and non-infarction groups.

Statistical methodology

For comparisons of categorical variables, Fischer's exact or χ^2 tests were used. For comparisons of continuous variables, the rank-sum or Student's (two-tailed) t test were used. Variables demonstrating a possible association with any infarction in the univariate analysis ($p < 0.1$) were assessed by multivariate logistic regression and by proportionate hazards analyses, using the backward stepwise elimination technique. Variables demonstrating an association with EI, LI, or PI in the univariate analysis ($p < 0.1$) were assessed using bivariate regression and log-rank analyses. Histograms illustrating the timing of any ACA infarctions are presented, and product-limit event curves and Cox proportionate hazards plots for the outcome of any infarction were constructed. Patients with missing data were excluded from individual analyses. For all analyses, $p < 0.05$ was considered statistically meaningful. All computations were performed using the SPSS v12 program.

Results

Study population general features

A total of 500 consecutive SAH patients were enrolled: 11 cases were excluded due to secondary SAH from trauma or AVM, and cerebral imaging was unavailable in 15 cases. Of the 474 study subjects, mean age was 55 years, 66 % were female, and 67 % Caucasian (20 % African American, 4 % Hispanic, 9 % Asian). A total of 36 patients (7.6 %) developed an ACA infarction in 59/948 (6.2 %) of arterial territories—15 (42 %) developed between days 0 and 3, 19 (53 %) occurred from days 4 to 15, 3 (8 %) were of indeterminate onset, and 11 (31 %) occurred postoperatively. Comparisons between patients with and without ACA infarction(s) are provided in Table 1, and the temporal distribution of infarcts for each patient is illustrated in Fig. 1.

Univariate analyses

In the univariate analysis (Table 1), tobacco use ($p = 0.031$), H/H grade 4/5 ($p < 0.001$), CT score 3/4 ($p = 0.010$), IVH ($p = 0.002$), ACA/ACom aneurysm ($p < 0.001$), and surgical clipping ($p = 0.040$) were associated with any ACA infarction. EI was associated with H/H grade 4/5 ($p < 0.001$), CT score 3/4 ($p = 0.005$), IVH ($p = 0.007$), ACA/ACom location ($p < 0.001$), and race—inversely for Caucasians ($p = 0.046$) and directly for Asians ($p = 0.041$). LI was associated with tobacco use ($p = 0.046$), H/H grade 4/5 ($p = 0.039$), ACA/ACom location ($p < 0.001$), and VS ($p = 0.021$). Only surgical clipping ($p = .045$) was associated with PI. Among infarct groups, ACA/ACom aneurysms were present in 63–71 % of cases, and VS ($V_m > 120$ cm/s) occurred in 50–63 % of cases. Any infarct occurred in 7 % of Caucasians, 7 % of Africans, 15 % of Hispanics, and 14 % of Asians, whereas EI occurred in 2 % of Caucasians, 3 % of Africans, 10 % of Hispanics, and 9 % of Asians.

Bivariate and log-rank analyses

In bivariate analyses (Table 3) EI was predicted by non-Caucasian race ($p = 0.032$), H/H grade 4/5 ($p < 0.001$), CT score 3/4 ($p = 0.006$), IVH ($p = 0.027$), and ACA/ACom aneurysms ($p = 0.001$). H/H grade 4/5 ($p = 0.040$), ACA/ACom location ($p < 0.001$), and VS ($p = 0.027$) predicted LI, and surgery predicted PI ($p = 0.044$). In log-rank analyses (Fig. 2) non-Caucasian race ($p = 0.024$), H/H grade 4/5 ($p < 0.001$), CT score 3/4 ($p = 0.003$), IVH ($p = 0.010$), and ACA/ACom aneurysm ($p < 0.001$) predicted EI. LI was predicted by ACA/ACom location ($p < 0.001$), and PI was predicted by surgery ($p = 0.046$).

Multivariate analyses

Logistic regression (Table 2) identified H/H grade 4/5 [OR 6.1 (95 % CI 2.4–15)], ACA/ACom aneurysms [10

Table 1 Demographic, clinical, radiological, and anatomic characteristics of patients with and without ACA infarction

	Infarction ($n = 36$)	No infarction ($n = 438$)	p value
Demographics			
Age (years)	53 ± 15	56 ± 13	0.887
Female (%)	67	66	0.934
Race (%)			
Caucasian	58	68	0.257
African	17	20	0.642
Hispanic	8	4	0.188
Asian	17	9	0.130
Medical history			
Hypertension (%)	61	63	0.820
Tobacco use (%)	74	56	**0.031**
SAH aspects			
H/H grade 4/5 (%)	56	24	**<0.001**
1	14	29	
2	0	9	
3	31	38	
4	44	18	
5	11	6	
CT imaging information			
CT score 3/4 (%)	44	25	**0.010**
0	0	3	
1	14	35	
2	42	38	
3	3	6	
4	42	19	
IVH (%)	83	58	**0.002**
Day of last CT (days)	12 ± 9	13 ± 6	0.486
Aneurysm aspects			
ACA/ACom (%)	71	22	**<0.001**
Clipping (%)	36	21	**0.040**
TCUS monitoring			
Max ACA V_m (cm/s)	112 ± 35	112 ± 42	0.992
ACA VS (%)			
$V_m > 100$ cm/s	65	56	0.308
$V_m > 120$ cm/s	50	37	0.135
$V_m > 150$ cm/s	21	18	0.753

For continuous variables, values represent mean ± SD, and statistical calculations performed using the non-parametric rank-sum test. History of tobacco use was not available for one patient, initial CT scans for scoring were unavailable in three patients, angiograms were non-diagnostic or not performed in 12 cases, no surgical or endovascular treatment was performed in 131 cases, and 27 patients had no bone windows for insonation of the ACA

ACA anterior cerebral artery, *TCUS* transcranial ultrasound, *VS* vasospasm, V_m mean velocity

p values less than 0.05 are kept in bold

(4.1–25)], and surgical clipping [3.3 (1.3–8.4)] as independent predictors of any infarction. Cox regression (Table 3) reinforced the predictive value of H/H grade 4/5 [HR 3.3 (95 % CI 1.6–6.7)], ACA/ACom location [8.3 (3.7–19)] and surgical clipping [2.66 (1.25–5.70)] for any infarction, and also identified CT score as an independent predictor [2.17 (1.03–4.57)]—event plots illustrated in Fig. 3. Due to the small number of outcomes in the EI/LI/PI groups, multivariate logistic or hazards regressions were not performed, and only results from bivariate and log-rank analyses are presented.

Discussion

The findings of our study indicate that ACA infarctions occur in approximately 8 % of all SAH patients, and that infarctions frequently occur in the acute period following rupture (42 % of cases in our investigation) [9], and not exclusively in the subacute period when vasospasm is typically expected. Additionally, our findings demonstrate that ACA/ACom aneurysm location and clinical severity are the most consistent predictors for any, early or late infarctions, that surgical clipping poses a greater risk for

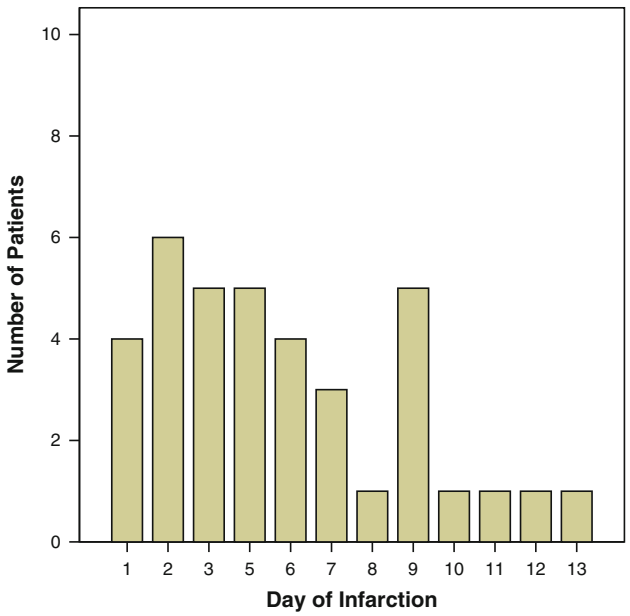

Fig. 1 Bar chart illustrating the timing of ACA infarctions. The figure displays the day of ACA infarction per patient and illustrates relatively equal distribution of infarctions during early (0–3 days) and late (4–15) periods

any and postoperative infarction compared to endovascular coiling, and that hemorrhage quantity predicts any and EIs. The results also demonstrate that race relates to EI, and that VS may relate to LI.

Our findings are consistent with the preponderance of prior studies connecting cerebral infarction to clinical grade [2, 6, 10–12], and with studies linking territory of infarction to ipsivascular aneurysm location [13]. The finding of an association between infarction and hemorrhage quantity in one of the two regression analyses is also consistent with previous reports variably identifying cisternal [10, 11] or intraventricular hemorrhage [6] (and hydrocephalus or ventriculostomy) [13] as ischemic predictors, and may also be indicative of the contrary reports in the literature [2, 4, 12, 14]. The increased frequency of any infarct and PI among surgically treated patients suggests greater mechanical disruption and vessel injury, or increased predisposition to alternative predisposing processes than when endovascular techniques are employed. However, the literature regarding risk of infarction according to treatment modality provides conflicting information, variably demonstrating greater risk from surgical clipping [15], greater risk from endovascular coiling [10], or equivalent risk [4, 16]. Nevertheless, surgical treatment has been more consistently linked to vasospasm and delayed ischemic neurological deficit (DIND) than endovascular therapy [15–17], and vasospasm and DIND have in turn been linked to greater probability for infarction following SAH [2, 4, 5, 10, 12, 14, 18, 19].

The relation between EI and clinical grade, hemorrhage quantity, and aneurysm location, has been noted by previous investigators [9, 20], as has the relation between LI and clinical grade, aneurysm location, and vasospasm [12, 13]. Proposed mechanisms for EI have included acute spasm, aneurysmal thromboembolization, and decreased cerebral perfusion [20]. The predictive value of clinical condition for LI supports delayed vasospasm as a prominent process in the development of infarctions during the subacute period, given the association between clinical status and vasospasm [21], and is reinforced by the finding of an relation between VS and LI. That EI were more frequent among Asians (and Hispanics numerically), while Caucasian race was inversely related to EI, is of uncertain significance given the small number of patients involved, which limits rigorous statistical analysis and allows for the possibility of a random finding. Conversely, recent studies have reported worse outcomes among non-Caucasians (mostly Hispanic) [22], and greater mortality among Asians (mostly women) [23], but do not specify infarction rate.

Table 2 Logistic regression analyses for any, early, late, and postoperative ACA infarctions

	Any		Early		Late		Postop	
	OR (95 % CI)	*p* value	OR (95 % CI)	*p* value	OR (95 % CI)	*p* value	OR (95 % CI)	*p* value
Caucasian	–		0.32 (0.11–0.91)	**0.032**	–		–	
Tobacco use	NS		–		3.0 (0.97–9)	0.058	–	
H/H grade 4/5	6.1 (2.4–15)	**<0.001**	8.3 (2.6–27)	**<0.001**	2.6 (1.0–6.6)	**0.040**	NS	
CT score 3/4	–		4.5 (1.6–12)	**0.006**	–		–	
IVH	2.6 (0.89–7.5)	0.080	10 (1.3–77)	**0.027**	2.6 (0.87–8)	0.088	–	
ACA/ACom location	10 (4.1–25)	**<0.001**	8.0 (2.5–26)	**0.001**	5.5 (2.1–14)	**<0.001**	–	
Surgical clipping	3.3 (1.3–8.4)	**0.011**	–		–		3.2 (1.03–9.7)	**0.044**
ACA VS ($V_m > 120$ cm/s)	–		–		2.9 (1.1–7.6)	**0.027**	2.7 (0.86–8.4)	0.088

Multivariate model for any ACA infarction incorporates tobacco use, H/H grade, CT score IVH, aneurysm location, and treatment type. For EI/LI/PI, only results from the bivariate analyses are presented. Only values with $p < 0.1$ are listed, and those with $p < 0.05$ are in *bold*

The findings of our study implicate alternate mechanisms to delayed vasospasm in the development of a substantial proportion of ACA infarctions, as several investigators have observed [4, 5, 9, 20]. The relatedness of EI with clinical severity and hemorrhage quantity suggests that acute processes such as inflammation, edema, and thrombosis may be contributory [9, 20]. Conversely, the absence of a connection between EI and VS fails to support early spasm as a cause of infarction during the acute period. The occurrence of VS in 63 % of LI is comparable to prior investigations reporting a 40–80 % concurrence rate [4, 5, 10, 12, 13, 17–19], and suggests that non-vasospastic mechanisms may prevail in the remaining cases. Finally, the independent predictive value of aneurysm location for any, EI, or LI provides additional evidence that focal processes aside from vasospasm may participate in the development of ACA ischemia.

Despite the non-modifiable nature of most identified risk factors for ACA infarction (including race, clinical status, hemorrhage amount, and aneurysm location),

Table 3 Proportional hazards analyses for any ACA infarctions

	Any infarct	
	HR (95 % CI)	*p* value
Tobacco use	NS	
H/H grade 4/5	3.89 (1.89–8.07)	**<0.001**
CT score 3/4	2.17 (1.03–4.57)	**0.042**
IVH	NS	
ACA/ACom location	8.87 (3.92–20)	**<0.001**
Surgery	2.66 (1.25–5.70)	**0.012**

Multivariate model incorporates tobacco use, H/H grade, CT score, IVH, aneurysm location, and treatment modality. Only values with $p < 0.1$ are listed, and those with $p < 0.05$ are in *bold*

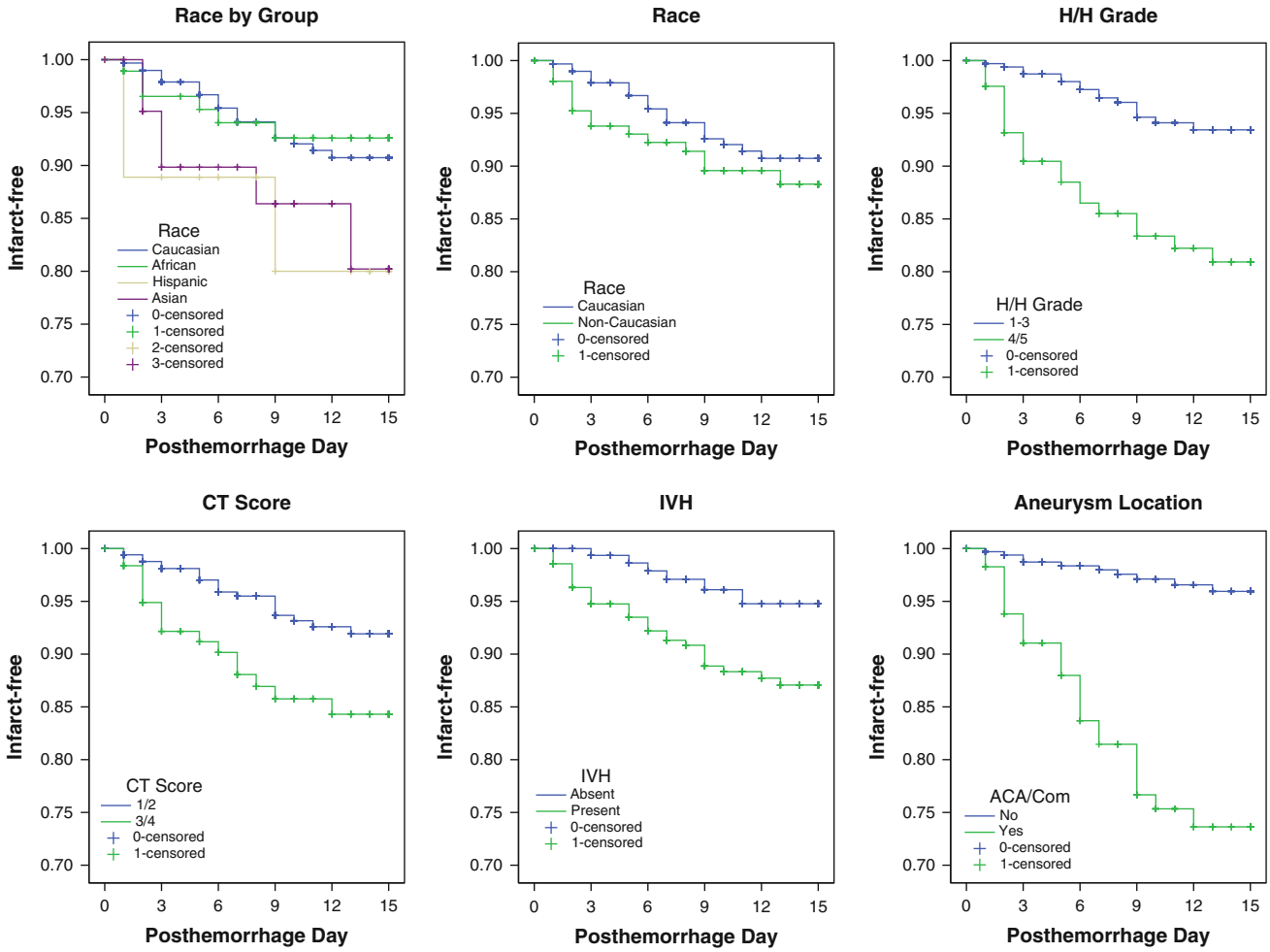

Fig. 2 Product-limit time–event curves for influence of variables upon any ACA infarction over time. Figures demonstrate the predictive value of non-Caucasian race (via Hispanics and Asians) upon EI ($p = 0.024$), H/H grade upon any ($p < 0.001$) and EI ($p < 0.001$), CT score upon any ($p = 0.013$) and EI ($p = 0.003$), IVH upon any ($p = 0.011$) and EI ($p = 0.010$), and ACA/ACom aneurysm location upon any ($p < 0.001$), EI ($p < 0.001$) and LI ($p < 0.001$). In addition, tobacco use tended to predict any ($p = 0.053$) and LI ($p = 0.067$), surgical treatment predicted PI ($p = 0.046$) and tended to predict any infarct ($p = 0.072$), and H/H grade tended to predict LI ($p = 0.050$). All p values were calculated using the log-rank test

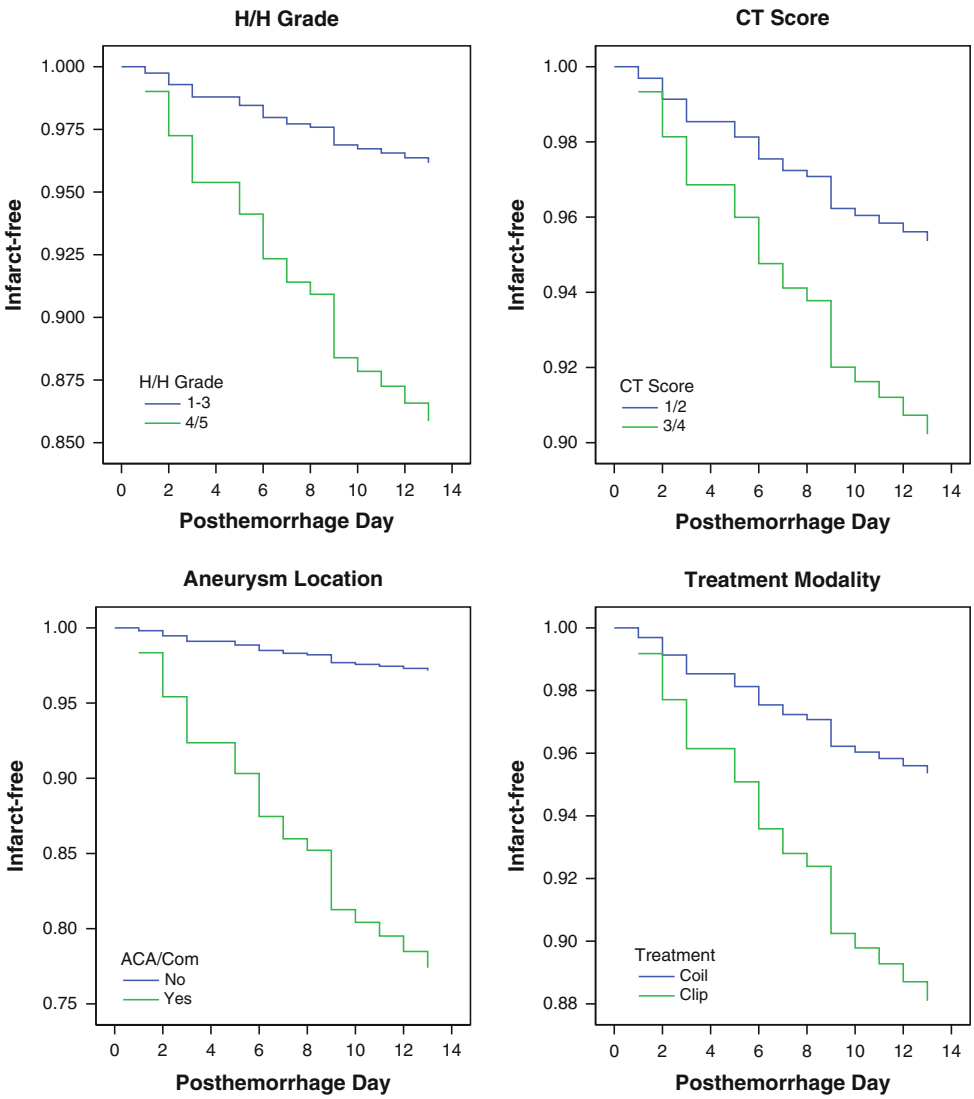

Fig. 3 Cox proportional hazards event plots for any ACA infarction. Event plots from Cox proportional hazards regression analyses per H/H grade, CT score, aneurysm location, and treatment modality. The figures illustrate substantially greater chance of ACA infarction over time with worse clinical grade, greater hemorrhage quantity, ACA/ACom aneurysm location, and surgical treatment

improvements in endovascular techniques may reduce or replace surgical procedures, and thereby decrease the occurrence of ischemic events [15, 16]. Additionally, since late infarction was increased in patients with severe clinical grade and in those with ACA/ACom aneurysms, greater vigilance in such cases may allow for earlier detection and treatment of ACA vasospasm and ischemia. Advancements in ultrasonographic technology [24] and greater utilization of CT/MR angiography and perfusion imaging [25, 26] may permit for more reliable and timely detection of ACA involvement.

Alternatively, continuous or readily reproducible physiologic monitoring may also be employed for the early detection of ACA compromise and ischemia. Noninvasive techniques such as TCUS or near-infrared spectroscopy (NIRS) quantification of flow and vascular autoregulation [27, 28], and continuous electroencephalography (cEEG) to identify early territorial ischemia have been proposed and utilized [29], as have invasive strategies such as thermodilution probes that measure local perfusion [30], and oxygenation or microdialysis probes to monitor for local tissue ischemia [31]. Such monitoring to detect early ACA compromise and/or ischemia may potentially allow for timely therapeutic interventions that prevent infarction. Based on current recommendations, medical management by induced hypertension and/or inotropic augmentation (in addition to ensuring euvolemia), and endovascular treatment for medically refractory symptoms may be considered [32].

As the main vascular supply to the medial frontal lobes, the ACAs perfuse prefrontal regions critical in controlling motivation, executive function, emotion, and personality [33]. In addition to derangements in prefrontal function, motor, sensory, sphincteric, language, spatial, apraxic, memory and complex disconnection syndromes may also be seen with ACA infarcts [34]. Among SAH patients,

neuropsychiatric deficits have been observed in >50 % of patients with ACA aneurysm ruptures [35], and between 20 and 25 % of those with ACom aneurysms (exceeding that from MCA aneurysms) [36, 37]. In a study assessing ACA/ACom ruptures, intellectual deficits were observed in two-thirds of patients, which resulted in substantially reduced employment and productivity [38].

Limitations to our study include the retrospective nature of data collection, the absence of imaging studies in some patients, and the exclusion of patients who expired prior to or immediately upon arrival that precluded enrollment. Major limitations include the inability to relate timing of infarction to presence or absence of vasospasm, the lack of angiographic identification of vasospasm, and the lack of MRI determination of infarction. Nevertheless, it remains pertinent that many infarctions developed at a time when vasospasm does not typically occur, and routinely obtaining angiography or MRI to assess for vasospasm or infarction may prove impractical given logistic difficulties and patient safety issues. Positive aspects of our investigation include the large number of patients studied, and the importance of our findings, which demonstrate that infarctions in the ACA territory are not uncommon, and which implicate non-vasospastic mechanisms in a substantial proportion of cases. A final attribute may be the unique nature of our investigation, since we are unaware of any prior studies specifically addressing ACA infarction in SAH.

Conclusions

In SAH patients, approximately 8 % develop ACA infarction, 42 % during the first 4 days. Risk factors for ACA infarction include clinical severity, hemorrhage quantity, aneurysm location, surgical treatment, and possibly non-Caucasian race. We postulate that mechanisms of infarction may include local inflammation, cerebral edema, thrombosis, surgical manipulation, and delayed vasospasm. Greater attention to the potential for ACA infarction, newer imaging modalities, and advances in endovascular techniques may minimize such events.

Approval/Consent This study was reviewed and approved by the Office of Human Research at Thomas Jefferson University Medical Center. No informed consent was required for study data acquisition or analysis.

Conflicts of interest The authors have no conflicts of interest to declare.

Ethical standard This study was performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki.

References

1. Nieuwkamp K, Setz L, Algra A, Linn F, de Rooij N, Rinkel G (2009) Changes in case fatality of aneurysmal subarachnoid hemorrhage over time according to age sex and region: a meta-analysis. Lancet Neurol 8:635–642
2. Ferguson S, Macdonald R (2007) Predictors of cerebral infarction in patients with aneurysmal subarachnoid hemorrhage. Neurosurgery 60:658–667
3. Rosengart A, Schultheiss K, Tolentino J, Macdonald L (2007) Prognostic factors for outcome in patients with aneurysmal subarachnoid hemorrhage. Stroke 38:2315–2321
4. Rabinstein A, Friedman J, Weigand S, McClelland R, Fulgham J, Manno E, Atkinson J, Wijdicks E (2004) Predictors of cerebral infarction in aneurysmal subarachnoid hemorrhage. Stroke 35:1862–1866
5. Vergouwen M, Ilodigwe D, Macdonald L (2011) Cerebral infarction after subarachnoid hemorrhage contributes to poor outcome by vasospasm-dependent and -independent effects. Stroke 42:924–929
6. Schmidt J, Wartenberg K, Fernandez A et al (2008) Frequency and clinical impact of asymptomatic cerebral infarction due to vasospasm after subarachnoid hemorrhage. J Neurosurg 109:1052–1059
7. Langlois O, Rabehenoina C, Proust F, Freger P, Tadie M, Creissard P (1992) Diagnosis of vasospasm: comparison between angiography and transcranial Doppler (A series of 112 comparative tests). Neurochirurgie 38:138–140
8. Kramer A, Hehir M, Nathan B, Gress D, Dumont A, Kassell N, Bleck T (2008) A comparison of 3 radiographic scales for the prediction of delayed ischemia and prognosis following subarachnoid hemorrhage. J Neurosurg 109:199–207
9. Naidech A, Drescher J, Tamul P, Shaibani A, Batjer H, Alberts M (2006) Acute physiological derangement is associated with early radiographic cerebral infarction after subarachnoid hemorrhage. J Neurol Neurosurg Psychiatry 77:1340–1344
10. Hoh B, Curry W, Carter B, Ogilvy C (2004) Computed tomographic demonstrated infarcts after surgical and endovascular treatment of aneurysmal subarachnoid hemorrhage. Acta Neurochir 146:1177–1183
11. Juvela S, Siironen J, Kuhmonen J (2005) Hyperglycemia, excess weight, and history of hypertension as risk factors for poor outcome and cerebral infarction after aneurysmal subarachnoid hemorrhage. J Neurosurg 102:998–1003
12. Crowley W, Medel R, Dumont A et al (2011) Angiographic vasospasm is strongly correlated with cerebral infarction after subarachnoid hemorrhage. Stroke 42:919–923
13. Rabinstein A, Weigand S, Atkinson J, Wijdicks E (2005) Patterns of cerebral infarction in aneurysmal subarachnoid hemorrhage. Stroke 36:992–997
14. Su F, Lin Y, Chang W et al (2010) Predictors and outcome of acute symptomatic cerebral infarctions following aneurysmal subarachnoid hemorrhage. J Neurol 257:264–270
15. Rabinstein A, Pichelmann M, Feriedman J et al (2003) Symptomatic vasospasm and outcomes following aneurysmal subarachnoid hemorrhage: a comparison between surgical repair and endovascular coil occlusion. J Neurosurg 98:319–325
16. Dumont A, Crowley W, Monteith S et al (2010) Endovascular treatment or neurosurgical clipping of ruptured intracranial aneurysms: effect on angiographic vasospasm, delayed ischemic neurological deficit, cerebral infarction, and clinical outcome. Stroke 41:2519–2524
17. Hohlrieder M, Spiegel M, Hinterhoelzl J et al (2002) Cerebral vasospasm and ischaemic infarction in clipped and coiled intracranial aneurysm patients. Eur J Neurol 9:389–399

18. Weidauer S, Lanfermann H, Raabe A, Zanella F, Seifert V, Beck J (2007) Impairment of cerebral perfusion and infarct patterns attributable to vasospasm after aneurysmal subarachnoid hemorrhage. Stroke 38:1831–1836
19. Dankbaar J, Rijsdijk M, van der Schaaf I, Velthuis B, Wermer M, Rinkel G (2009) Relationship between vasospasm, cerebral perfusion, and delayed cerebral ischemia after aneurysmal subarachnoid hemorrhage. Neuroradiology 51:813–819
20. Schmidt J, Rincon F, Fernandez A et al (2007) Cerebral infarction associated with acute subarachnoid hemorrhage. Neurocrit Care 7:10–17
21. Harrod C, Bendok B, Batjer H (2005) Prediction of cerebral vasospasm in patients presenting with aneurysmal subarachnoid hemorrhage. Neurosurgery 56:633–654
22. Zacharia B, Grobelny B, Komotar R, Connolly S, Mocco J (2010) The influence of race on outcome following subarachnoid hemorrhage. J Clin Neurosci 17:34–37
23. Schievink W, Riedinger M, Jhutty T, Simon P (2004) Racial disparities in subarachnoid hemorrhage mortality: Los Angeles County, California, 1985–1998. Neuroepidemiology 23:299–305
24. White H, Balasubramanian V (2006) Applications of transcranial Doppler in the ICU: a review. Intensive Care Med 32:981–994
25. Greenberg E, Gold R, Reichman M et al (2010) Diagnostic accuracy of CT angiography and CT perfusion for cerebral vasospasm: a meta-analysis. AJNR 31:1853–1860
26. Hertel F, Walter C, Bettag M, Morsdorf M (2005) Perfusion magnetic resonance imaging in patients with vasospasm: a useful new tool in the management of patients with subarachnoid hemorrhage. Neurosurgery 56:28–35
27. Ratsep T, Asser T (2001) Cerebral hemodynamic impairment after aneurysmal subarachnoid hemorrhage as evaluated using transcranial Doppler ultrasonography: relationship to delayed cerebral ischemia and clinical outcome. J Neurosurg 95:393–401
28. Yokose N, Sakatani K, Murata Y, Awano T, Igarashi T, Nakamura S, Hoshino T, Katayama Y (2010) Bedside monitoring of cerebral blood oxygenation and hemodynamics after aneurysmal subarachnoid hemorrhage by quantitative time-resolved near-infrared spectroscopy. World Neurosurg 73:508–513
29. Claassen J, Hirsch L, Kreiter K, Du E, Connolly S, Emerson R, Mayer S (2004) Quantitative continuous EEG for detecting delayed cerebral ischemia in patients with poor grade subarachnoid hemorrhage. Clin Neurophysiol 115:2699–2710
30. Goodman J, Valadka A, Gopinath S, Uzura M, Robertson C (1999) Extracellular lactate and glucose alterations in the brain after head injury measured by microdialysis. Crit Care Med 27:1965–1973
31. Helbok R, Madineni R, Schmidt J et al (2011) Intracerebral monitoring of silent infarcts after subarachnoid hemorrhage. Neurocrit Care 14:162–167
32. Diringer M, Bleck T, Hemphill J et al (2011) Critical care management of patients following aneurysmal subarachnoid hemorrhage: recommendations from the Neurocritical Care Society's Multidisciplinary Consensus Conference. Neurocrit Care 15:211–240
33. Berman S, Hayman L, Hinck V (1980) Correlation of CT cerebral vascular territories with function: anterior cerebral artery. AJR 135:253–257
34. Bogousslavsky J, Regli F (1990) Anterior cerebral artery territorial infarction in the Lausanne stroke registry: clinical and etiologic patterns. Arch Neurol 47:144–150
35. Bendel P, Koivisto T, Niskanen E, Kononen M, Aikia M, Hanninen T, Koskenkorva P, Vannienen R (2009) Brain atrophy and neuropsychological outcome after treatment of ruptured anterior cerebral artery aneurysms: a voxel-based morphometric study. Neuroradiology 51:711–722
36. Proust F, Martinaud O, Gerardin E et al (2009) Quality of life and brain damage after microsurgical clip occlusion or endovascular coil embolization for ruptured anterior communicating artery aneurysms: neuropsychological assessment. J Neurosurg 110:19–29
37. Haug T, Sorteberg A, Sorteberg W, Lindegaard K, Lundar T, Finset A (2009) Cognitive functioning and health related quality of life after rupture of an aneurysm on the anterior communicating artery versus middle cerebral artery. Br J Neurosurg 23:507–515
38. Bindschaedler C, Assal G, de Tribolet N (1997) Cognitive sequelae following rupture of aneurysms of the anterior communicating artery and the anterior cerebral artery: retrospective study of 56 cases. Rev Neurol (Paris) 153:669–678