



## Neurogenic Stress Cardiomyopathy After Aneurysmal Subarachnoid Hemorrhage

**Athar N. Malik, Bradley A. Gross, Pui Man Rosalind Lai, Ziev B. Moses, Rose Du**

■ **BACKGROUND:** Neurogenic stress cardiomyopathy (NSC) is a known complication of aneurysmal subarachnoid hemorrhage (SAH). Detailed analyses of risk factors for its occurrence across large cohorts are relatively sparse.

■ **METHODS:** A consecutive group of 300 patients with aneurysmal SAH was reviewed for the presence of markers of myocardial injury, including electrocardiogram changes (long QT, T-wave inversion), elevated plasma troponin levels ( $\geq 0.1$ ), and echocardiogram findings (decreased ejection fraction and wall motion abnormalities). NSC was defined as the presence of at least 1 marker of myocardial injury. Univariate and multivariate analyses were conducted to assess the correlation of NSC and individual markers of myocardial injury with age, gender, medical comorbidities, medications, current smoking status, Hunt-Hess grade, and Fisher grade. Medical comorbidities were assessed based on reported medical history or reported use of comorbidity-specific medications at the time of presentation.

■ **RESULTS:** Across the cohort, 27% of patients had a plasma troponin elevation of at least 0.1; 13%, a prolonged QT interval; 16%, new T-wave inversions; 18%, a depressed ejection fraction (<55%); and 15%, echocardiographic wall motion abnormalities. After a multivariate analysis, significant risk factors for NSC included higher Hunt-Hess grade on presentation (odds ratio [OR] = 2.33,  $P = 4.52 \times 10^{-6}$ ), current smoking status (OR = 2.00,  $P = 0.030$ ), and older age (OR = 1.03,  $P = 0.048$ ). Hypertension was protective against NSC (OR = 0.48,  $P = 0.031$ ). Patient gender, hyperlipidemia,

diabetes, coronary artery disease, statin use, beta blocker use, angiotensin-converting enzyme inhibitor use, aspirin use, and thicker SAH (Fisher grade 3) were not significant risk factors for NSC.

■ **CONCLUSIONS:** Higher Hunt-Hess grade, current smoking status, lack of hypertension, and older age were the strongest predictors of NSC.

### INTRODUCTION

Myocardial injury is a known complication of aneurysmal subarachnoid hemorrhage (SAH) (9). The elevation in intracranial pressure secondary to aneurysmal SAH is thought to cause sympathetic activation resulting in hypercontraction of cardiac myocytes and subsequent myocardial injury (9). Although this phenomenon has been described by various names, including neurogenic myocardial stunning (8) and neurocardiogenic injury (14), it is now commonly referred to as neurogenic stress cardiomyopathy (NSC) to reflect more accurately the accepted underlying pathophysiology (9). Clinically, NSC may manifest as electrocardiogram (ECG) changes including prolonged QT interval and T-wave changes (6), elevated troponin levels (11), or echocardiographic findings including reduced ejection fraction (EF) and wall motion abnormalities (12). Detailed analyses of risk factors for its occurrence across large cohorts are sparse, and no studies to date have evaluated the impact of medical comorbidities, current medications, and current smoking status on the development of NSC. In this study, we evaluated a single institutional cohort to elucidate further risk factors for NSC after aneurysmal SAH.

### Key words

- Aneurysm
- Myocardial
- Neurogenic stress cardiomyopathy
- Stress
- Stunning
- Subarachnoid hemorrhage
- Troponin

### Abbreviations and Acronyms

- ACE:** Angiotensin-converting enzyme  
**ECG:** Electrocardiogram  
**EF:** Ejection fraction  
**HH:** Hunt-Hess  
**NSC:** Neurogenic stress cardiomyopathy

**OR:** Odds ratio

**SAH:** Subarachnoid hemorrhage

**Tnl:** Troponin I

*Department of Neurological Surgery, Brigham and Women's Hospital and Harvard Medical School, Boston, Massachusetts, USA*

*To whom correspondence should be addressed: Bradley A. Gross, M.D.  
 [E-mail: bgross1@partners.org]*

*Citation: World Neurosurg. (2015) 83, 6:880-885.  
<http://dx.doi.org/10.1016/j.wneu.2015.01.013>*

*Journal homepage: [www.WORLDNEUROSURGERY.org](http://www.WORLDNEUROSURGERY.org)*

*Available online: [www.sciencedirect.com](http://www.sciencedirect.com)*

*1878-8750/\$ - see front matter © 2015 Elsevier Inc. All rights reserved.*

## MATERIALS AND METHODS

With approval of our local institutional review board, we reviewed the records of a consecutive series of 300 patients with aneurysmal SAH. We extracted patient age, gender, pertinent medical comorbidities (hypertension, hyperlipidemia, diabetes, coronary artery disease), medication use on presentation (statin, beta blocker, angiotensin-converting enzyme [ACE] inhibitor, aspirin), current smoking status, presenting Hunt-Hess (HH) grade, and SAH thickness. Medical comorbidities were considered present based on reported medical history or reported use of comorbidity-specific medications at the time of presentation. We noted pertinent ECG findings on presentation (prolonged QT interval, T-wave changes), maximum troponin I (TnI) levels within 72 hours of presentation, and pertinent echocardiogram findings within 72 hours of presentation (EF and wall motion abnormalities). ECG and echocardiogram findings are based on the results reported in the medical records as reviewed by a cardiologist. Outcome was measured by the modified Rankin Scale. A modified Rankin Scale score of  $\geq 3$  at discharge was defined as poor outcome.

Statistical analysis was performed using R (version 3.0.2). NSC was defined as the presence of at least 1 marker of myocardial injury (troponin  $\geq 0.1$ , EF  $< 55\%$ , long QT, T-wave inversions, wall motion abnormalities). Univariate and multivariate logistic regressions were conducted to assess risk factors for QT prolongation, T-wave inversions, elevated plasma troponin, depressed EF ( $EF < 55\%$ ), wall motion abnormalities, and overall NSC. The following variables were evaluated: age, gender, medical comorbidities, current medications, current smoking status, clinical grade (H-H), and radiographic grade (Fisher). Missing data were excluded from the analysis. Statistical significance was defined as  $P < 0.05$ .

## RESULTS

Of 300 consecutive patients seen at our institution with confirmed aneurysmal SAH, 14 did not have early posthemorrhage troponin and echocardiographic data and were excluded from the analysis. Mean age for the overall evaluated cohort was  $54.9 \text{ years} \pm 14.2$  with a female predilection (76%). Associated medical conditions included hypertension in 47% of patients, hyperlipidemia in 20%, diabetes mellitus in 6%, and coronary artery disease in 7%. Medications included statins (11%), beta blockers (14%), ACE inhibitors (10%), and aspirin (13%). Of patients, 39% were current smokers. Poor clinical grade at presentation (HH 4–5) was seen in 27% of patients. Thick subarachnoid clot (Fisher grade of 3, at least 1 mm thick) was seen on computed tomography in 67% of patients (Table 1).

### ECG Changes

13% of the patients had QT prolongation on initial ECG, and 16% had T-wave changes. After multivariate analysis (Table 2), age, gender, prior medical conditions (hypertension, hyperlipidemia, diabetes, coronary artery disease), medication use (statin, beta blocker, ACE inhibitor, aspirin), current smoking status, and HH and Fisher grades were not significantly associated with QT prolongation. T-wave inversion was positively correlated with HH grade (odds ratio [OR] = 2.24,  $P = 4.7 \times 10^{-4}$ ), use of beta blockers (OR = 5.85,  $P = 0.007$ ), and female gender (OR = 5.51,  $P = 0.007$ ). T-wave inversion was negatively correlated with use of statins (OR = 0.03,  $P = 0.032$ ). Other factors, such as age, prior medical

conditions (hypertension, hyperlipidemia, diabetes, coronary artery disease), other medication use (ACE inhibitor, aspirin), current smoking status, and Fisher grade, were not significant risk factors for the occurrence of T-wave inversions at presentation.

### Elevated Plasma TnI

Overall, 37% of patients had elevated plasma TnI within 72 hours of presentation. Of patients, 10% had a minimal elevation (TnI  $0.01\text{--}0.1$ ), 15% had a moderate elevation (TnI  $0.1\text{--}1.0$ ), and 12% had a significant elevation (TnI  $>1.0$ ) (Table 1). In multivariate analysis (Table 2), a significant TnI elevation ( $\geq 0.1$ ) was positively correlated with HH grade (OR = 2.45,  $P = 7.6 \times 10^{-6}$ ) and age (OR = 1.03,  $P = 0.032$ ) but negatively correlated with hypertension (OR = 0.47,  $P = 0.047$ ). Gender, other medical conditions (hyperlipidemia, diabetes, coronary artery disease), medication use (statin, beta blocker, ACE inhibitor, aspirin), current smoking status, and Fisher grade were not significant risk factors for significant TnI elevation ( $\geq 0.1$ ).

### Low EF (<50%)

Of the 286 patients with TnI data, 169 underwent echocardiography (59%) (Table 1). Of these 169 patients, 82 did not have a TnI elevation (49%), 22 had a minimal TnI elevation (13%;  $0.01\text{--}0.1$ ), 35 had a moderate TnI elevation (21%;  $0.1\text{--}1.0$ ), and 30 had a TnI elevation of at least 1.0 (18%). There were 31 patients with an EF  $< 55\%$  (18% of cases); 4 of these patients had an EF of  $\leq 30\%$ . T-wave changes on ECG were demonstrated in 13 of these patients (42%). In a multivariate analysis (Table 2), reduced EF ( $< 55\%$ ) was positively correlated with HH grade (OR = 1.91,  $P = 0.033$ ) and statin use (OR = 19.8,  $P = 0.043$ ) and negatively correlated with hypertension (OR = 0.12,  $P = 0.006$ ). Patient age, gender, other medical conditions (hyperlipidemia, diabetes, coronary artery disease), other medication use (beta blocker, ACE inhibitor, statin), current smoking status, and Fisher grade were not significant risk factors for a depressed EF on echocardiography.

### Wall Motion Abnormalities

Of the 169 patients who underwent echocardiography, 25 exhibited wall motion abnormalities (15%) (Table 1). Nearly half of these patients demonstrated T-wave inversions on ECG (12 of 25 [48%]), and most had thick SAH (Fisher grade 3; 23 of 25 [92%]). In a multivariate analysis (Table 2), the presence of wall motion abnormalities was positively correlated with HH grade (OR = 2.05,  $P = 0.036$ ) and negatively correlated with hypertension (OR = 0.14,  $P = 0.021$ ). Patient age, gender, other medical conditions (hyperlipidemia, diabetes, coronary artery disease), medication use (statin, beta blocker, ACE inhibitor, statin), current smoking status, and Fisher grade were not significant risk factors for the presence of wall motion abnormalities.

Of the 25 patients with wall motion abnormalities, 7 patients exhibited apical hypokinesis (Takotsubo cardiomyopathy; 28%), 12 patients exhibited nonapical hypokinesis (48%), and 6 patients exhibited global hypokinesis (24%) (Table 3). All 7 patients with apical hypokinesis were female, all had thick SAH, and the mean age of these patients was 74.6 years (SD 9.3). Background and demographic characteristics of patients with nonapical hypokinesis and global hypokinesis did not significantly differ from our general cohort (Table 3).

**Table 1.** Characteristics of All Patients and Patients with Troponin Leaks, Ejection Fraction <55%, and Wall Motion Abnormalities

	Overall	Troponin Leak	EF <55%	Any WMA
Patients	286	107/286 (37%)	31/169 (18%)	25/169 (15%)
Age (years) (mean ± SD)	54.9 (14.2)	58.9 (14.3)	60.4 (15.8)	58.8 (15.5)
Female gender	216/286 (76%)	83/107 (78%)	26/31 (84%)	20/25 (80%)
Medical history				
Hypertension	135/286 (47%)	48/107 (45%)	8/31 (26%)	6/25 (24%)
Hyperlipidemia	56/286 (20%)	19/107 (18%)	4/31 (13%)	2/25 (8%)
Diabetes	18/286 (6%)	7/107 (7%)	2/31 (6%)	1/25 (4%)
CAD	20/286 (7%)	10/107 (9%)	4/31 (13%)	3/25 (12%)
Medications				
Statin	32/286 (11%)	12/107 (11%)	5/31 (16%)	3/25 (12%)
Beta blocker	39/286 (14%)	16/107 (15%)	6/31 (19%)	4/25 (16%)
ACE inhibitor	28/286 (10%)	10/107 (9%)	1/31 (3%)	1/25 (4%)
Aspirin	38/286 (13%)	14/107 (13%)	2/31 (6%)	1/25 (4%)
Current smoker	112/286 (39%)	44/107 (41%)	12/31 (39%)	10/25 (40%)
Hunt-Hess 4–5	77/286 (27%)	56/107 (52%)	20/31 (65%)	18/25 (72%)
Thick SAH*	193/286 (67%)	91/107 (85%)	28/31 (90%)	23/25 (92%)
ECG changes				
QT prolonged	36/286 (13%)	22/107 (21%)	5/31 (16%)	3/25 (12%)
T-wave changes	45/286 (16%)	40/107 (37%)	13/31 (42%)	12/25 (48%)

EF, ejection fraction; WMA, wall motion abnormality; CAD, coronary artery disease; ACE, angiotensin-converting enzyme; SAH, subarachnoid hemorrhage; ECG, electrocardiogram.

\*Thick SAH indicates Fisher grade 3 SAH.

## NSC

NSC was defined as the presence of at least 1 marker of myocardial injury among the following markers: TnI  $\geq 0.1$ , EF  $<55\%$ , long QT, T-wave inversions, and wall motion abnormalities. In multivariate analysis (Table 4), NSC was positively correlated with HH grade ( $OR = 2.33$ ,  $P = 4.52 \times 10^{-6}$ ), current smoking status ( $OR = 2.00$ ,  $P = 0.030$ ), and older age ( $OR = 1.03$ ,  $P = 0.048$ ). NSC was negatively correlated with hypertension ( $OR = 0.48$ ,  $P = 0.031$ ). Patient gender, other medical conditions (hyperlipidemia, diabetes, coronary artery disease), medication use (statin, beta blocker, aspirin), and thicker SAH (Fisher grade 3) were not significant risk factors for NSC in this cohort.

## Outcome

Outcome at discharge was adversely affected by age ( $OR = 1.08$ ,  $P = 2.31 \times 10^{-4}$ ) and HH grade ( $OR = 2.15$ ,  $P = 0.006$ ) but not by NSC in multivariate analysis.

## DISCUSSION

Aneurysmal SAH is a devastating condition that is associated with mortality rates of up to 50% (3, 4). Although initial hemorrhage (2) and subsequent delayed cerebral ischemia (13) are major contributors to mortality, a more recent study found that NSC after aneurysmal SAH was also associated with higher mortality (7).

As a result, better understanding of the risk factors for the development of NSC after aneurysmal SAH may aid in the early recognition and treatment of NSC and improve patient outcome.

Detailed analyses of risk factors for occurrence of NSC after aneurysmal SAH across large cohorts are sparse. However, previous studies identified severity of neurologic injury as a major predictor of NSC after aneurysmal SAH, with patients presenting as HH grade  $>3$  having higher risk (5, 7, 14). Our study found that NSC was positively correlated with HH grade ( $OR = 2.33$ ,  $P = 4.52 \times 10^{-6}$ ) and is in line with these previous reports. This association supports the hypothesis that cardiac injury after SAH is a neurally mediated process. Previous studies also reported female gender as a risk factor for NSC after aneurysmal SAH (10, 14). In our study, although female gender was not a statistically significant risk factor for NSC ( $OR = 1.32$ ,  $P = 0.454$ ), it was a significant risk factor for T-wave inversions ( $OR = 5.51$ ,  $P = 0.007$ ). Our study also found that NSC was positively correlated with increasing age (multivariate  $OR = 1.03$ ,  $P = 0.048$ ). This result has not been previously reported but may reflect the reduced ability of older myocardium to withstand neurogenic stress in the context of aneurysmal SAH.

We assessed the impact of medical comorbidities, current medications, current smoking status, and radiographic SAH grade (Fisher grade) on development of NSC after aneurysmal SAH. We found that current smoking status was a risk factor for NSC ( $OR = 2.00$ ,  $P = 0.030$ ), and hypertension was protective against

**Table 2.** Results of Multivariate Analysis of Risk Factors for Individual Markers of Myocardial Injury

	Long QT			TWI			Troponin $\geq 0.1$			EF <55%			WMA		
	OR	95% CI	P Value	OR	95% CI	P Value	OR	95% CI	P Value	OR	95% CI	P Value	OR	95% CI	P Value
Age	1.00	0.97–1.04	0.852	1.01	0.97–1.04	0.718	1.03	1.00–1.06	0.032*	1.04	1.00–1.10	0.083	1.03	0.98–1.09	0.244
Female gender	0.75	0.29–2.06	0.565	5.51	1.77–22.2	0.007*	1.96	0.85–4.79	0.124	1.47	0.45–5.43	0.539	1.31	0.37–5.47	0.688
Medical history															
Hypertension	0.76	0.27–1.99	0.585	0.51	0.20–1.22	0.141	0.47	0.22–0.98	0.047*	0.12	0.02–0.46	0.006*	0.14	0.02–0.61	0.021*
Hyperlipidemia	1.79	0.44–6.59	0.392	2.43	0.54–9.86	0.224	1.50	0.46–4.68	0.490	0.13	0.00–1.17	0.119	0.40	0.01–4.41	0.498
Diabetes	0.45	0.02–2.89	0.478	1.67	0.31–8.02	0.527	0.71	0.15–2.91	0.641	6.40	0.55–69.2	0.119	2.60	0.07–45.8	0.531
CAD	0.37	0.02–3.31	0.427	3.18	0.24–40.4	0.351	3.04	0.52–18.6	0.214	1.51	0.05–25.0	0.775	6.37	0.17–341	0.291
Medications															
Statin	0.57	0.10–2.98	0.504	0.03	0.00–0.43	0.032*	0.41	0.08–1.85	0.254	19.8	1.51–706	0.043*	5.05	0.28–159	0.286
Beta blocker	0.25	0.03–1.24	0.132	5.85	1.62–21.9	0.007*	0.86	0.24–2.79	0.802	1.60	0.29–7.85	0.564	2.63	0.38–16.1	0.297
ACE inhibitor	4.01	0.95–16.4	0.052	0.82	0.08–4.83	0.845	0.73	0.16–2.91	0.667	0.47	0.01–7.05	0.630	3.92	0.15–57.8	0.323
Aspirin	3.21	0.92–10.7	0.060	0.09	0.00–0.74	0.071	0.44	0.11–1.52	0.219	0.09	0.00–1.46	0.155	$7.9 \times 10^{-9}$	$0\text{--}3.2 \times 10^{24}$	0.988
Current smoker	1.13	0.47–2.68	0.786	1.50	0.66–3.44	0.336	1.57	0.79–3.17	0.199	1.88	0.65–5.65	0.247	2.25	0.69–7.90	0.188
Hunt-Hess 4–5	1.44	0.90–2.36	0.137	2.24	1.45–3.61	$4.7 \times 10^{-4}*_{\dagger}$	2.45	1.68–3.71	$7.6 \times 10^{-6}*_{\dagger}$	1.91	1.08–3.63	0.033*	2.05	1.09–4.24	0.036*
Thick SAH <sup>†</sup>	2.26	0.66–9.27	0.216	1.66	0.54–5.52	0.383	1.54	0.60–4.15	0.377	0.89	0.17–5.51	0.895	1.05	0.16–9.57	0.959

Markers of myocardial injury included QT prolongation, T-wave inversion, troponin leak ( $\geq 0.1$ ), depressed ejection fraction (<55%), and wall motion abnormalities.

TWI, T-wave inversions; EF, ejection fraction; WMA, wall motion abnormalities; OR, odds ratio; CI, confidence interval; CAD, coronary artery disease; ACE, angiotensin-converting enzyme; SAH, subarachnoid.

\*P values meeting statistical significance ( $P < 0.05$ ).

†Thick SAH indicates Fisher grade 3 SAH.

**Table 3.** Characteristics of Patients with Different Patterns of Wall Motion Abnormalities on Echocardiography

	Apical Hypokinesis	Nonapical Hypokinesis	Global Hypokinesis
Patients	7	12	6
Age (years), mean (SD)	74.6 (9.3)	52.3 (14.9)	53.5 (8.9)
Female gender	7/7 (100%)	8/12 (67%)	5/6 (83%)
Medical history			
Hypertension	3/7 (43%)	3/12 (25%)	0/6 (0%)
Hyperlipidemia	0/7 (0%)	1/12 (8%)	1/6 (17%)
Diabetes	1/7 (14%)	0/12 (0%)	0/6 (0%)
CAD	2/7 (29%)	0/12 (0%)	1/6 (17%)
Medications			
Statin	1/7 (14%)	1/12 (8%)	1/6 (17%)
Beta blocker	3/7 (43%)	0/12 (0%)	1/6 (17%)
ACE inhibitor	0/7 (0%)	1/12 (8%)	0/6 (0%)
Aspirin	1/7 (14%)	0/12 (0%)	0/6 (0%)
Current smoker	1/7 (14%)	5/12 (42%)	4/6 (67%)
Hunt-Hess 4–5	4/7 (57%)	10/12 (83%)	4/6 (67%)
Thick SAH*	7/7 (100%)	11/12 (92%)	5/6 (83%)
ECG changes			
QT Prolonged	0/7 (0%)	3/12 (25%)	0/6 (0%)
T-wave changes	5/7 (71%)	5/12 (42%)	2/6 (33%)

CAD, coronary artery disease; ACE, angiotensin-converting enzyme; SAH, subarachnoid hemorrhage; ICA, internal carotid artery; ECG, electrocardiogram.

\*Thick SAH indicates Fisher grade 3 SAH.

**Table 4.** Results of Multivariate Analysis of Risk Factors for Neurogenic Stress Cardiomyopathy, Defined as the Presence of at Least 1 Marker of Myocardial Injury

	NSC		
	OR	95% CI	P
Age	1.03	1.00–1.05	0.048*
Female gender	1.32	0.64–2.78	0.454
Medical history			
Hypertension	0.48	0.24–0.93	0.031*
Hyperlipidemia	1.62	0.59–4.40	0.343
Diabetes	1.20	0.33–4.36	0.775
CAD	0.85	0.17–3.97	0.833
Medications			
Statin	0.42	0.11–1.52	0.189
Beta blocker	1.91	0.70–5.24	0.204
ACE inhibitor	1.09	0.34–3.40	0.887
Aspirin	0.85	0.28–2.40	0.757
Current smoker	2.00	1.08–3.78	0.030*
Hunt-Hess 4–5	2.33	1.65–3.40	4.52 × 10 <sup>-6</sup> *
Thick SAH†	1.27	0.59–2.77	0.550

Markers of myocardial injury included QT prolongation, T-wave inversion, troponin leak ( $\geq 0.1$ ), depressed ejection fraction ( $< 55\%$ ), and wall motion abnormalities.

NSC, neurogenic stress cardiomyopathy; OR, odds ratio; CI, confidence interval; CAD, coronary artery disease; ACE, angiotensin-converting enzyme; SAH, subarachnoid hemorrhage.

\*P values meeting statistical significance ( $P < 0.05$ ).

†Thick SAH indicates Fisher grade 3 SAH.

NSC (OR = 0.48,  $P = 0.031$ ). Other medical conditions (hyperlipidemia, diabetes, coronary artery disease), medication use (statins, beta blocker, ACE inhibitor, aspirin), and thicker SAH (Fisher grade 3) were not significant risk factors for NSC in this cohort.

In addition to finding a negative correlation between hypertension and NSC, we found that a history of hypertension was negatively correlated with the individual markers of myocardial injury, including elevated troponin levels ( $\geq 0.1$ ; OR = 0.47,  $P = 0.047$ ) and reduced EF (OR = 0.12,  $P = 0.006$ ). Although it may be assumed that a history of hypertension would place a patient at increased rather than decreased risk for myocardial injury after aneurysmal SAH, our results suggest otherwise. It is possible that a history of hypertension may result in preconditioning of the myocardium that makes it more resistant to the stress encountered during NSC. A previous study of the risk factors of NSC after aneurysmal SAH also found that lower systolic blood pressure was an independent predictor of troponin elevation (14). Additional studies are needed to understand this association better.

We did not observe a significant effect of NSC on outcome at discharge; this is in contrast to previous results reported by Kilbourn et al. (7). These authors found that NSC was associated with

poorer long-term functional outcomes. The poorer outcome in the earlier study may be due to differences in follow-up interval and the difference in the definition of myocardial dysfunction.

This study is limited by its single-center, retrospective design. The study also is impacted by not controlling for approximate time to presentation to our institution. As a result, there may be bias introduced by the variability in the time after aneurysmal SAH at which point clinical data were collected at our institution. Because NSC is a generally transient state (1), we may have missed peak occurrences of clinical indicators of NSC in some instances. Another limitation of our study may be the definition used to define and quantify NSC. In this study, NSC was a binary variable, defined by the presence of at least 1 marker of myocardial injury, including QT prolongation on ECG, T-wave inversion on ECG, elevated TnI levels ( $\geq 0.1$ ), reduced EF ( $< 55\%$ ), and wall motion abnormalities. We employed this definition to encompass the multiple variables that serve as clinical indicators of myocardial injury in NSC. Because this precise definition was not used in previous studies of NSC (5, 7, 14), the results of our study may not be directly comparable with prior studies.

We explored alternative methods of quantifying NSC. For example, we defined NSC not as a binary variable but instead as the sum of the number of individual markers of myocardial injury present. With this analysis, we obtained similar major results to those described. Our results appear to be robust to the exact definition of NSC used. Finally, our results may be affected by interobserver variability in HH grades.

## CONCLUSIONS

This study illustrates a statistically significant association of higher HH grade, current smoking status, older age, and lack of

hypertension with the risk of developing NSC after aneurysmal SAH. These findings build on previous studies that have investigated risk factors for NSC after aneurysmal SAH and support the hypothesis that cardiac injury after SAH is a neurally mediated process.

## ACKNOWLEDGMENTS

Dr. Malik received support from award number T32GM007753 from the National Institute of General Medical Sciences.

## REFERENCES

1. Banki N, Kopelnik A, Tung P, Lawton MT, Gress D, Drew B, Dae M, Foster E, Parmley W, Zaroff J: Prospective analysis of prevalence, distribution, and rate of recovery of left ventricular systolic dysfunction in patients with subarachnoid hemorrhage. *J Neurosurg* 105:15-20, 2006.
2. Broderick JP, Brott TG, Duldner JE, Tomsick T, Leach A: Initial and recurrent bleeding are the major causes of death following subarachnoid hemorrhage. *Stroke* 25:1342-1347, 1994.
3. Hijdra A, Braakman R, van Gijn J, Vermeulen M, van Crevel H: Aneurysmal subarachnoid hemorrhage. Complications and outcome in a hospital population. *Stroke* 18:1061-1067, 1987.
4. Hop JW, Rinkel GJ, Algra A, van Gijn J: Case-fatality rates and functional outcome after subarachnoid hemorrhage: a systematic review. *Stroke* 28:660-664, 1997.
5. Hravnak M, Frangiskakis JM, Crago EA, Chang Y, Tanabe M, Gorcsan J 3rd, Horowitz MB: Elevated cardiac troponin I and relationship to persistence of electrocardiographic and echocardiographic abnormalities after aneurysmal subarachnoid hemorrhage. *Stroke* 40:3478-3484, 2009.
6. Khechinashvili G, Asplund K: Electrocardiographic changes in patients with acute stroke: a systematic review. *Cerebrovasc Dis* 14:67-76, 2002.
7. Kilbourn KJ, Levy S, Staff I, Kureshi I, McCullough L: Clinical characteristics and outcomes of neurogenic stress cardiomyopathy in aneurysmal subarachnoid hemorrhage. *Clin Neurol Neurosurg* 115:909-914, 2013.
8. Kono T, Morita H, Kuroiwa T, Onaka H, Takatsuka H, Fujiwara A: Left ventricular wall motion abnormalities in patients with subarachnoid hemorrhage: neurogenic stunned myocardium. *J Am Coll Cardiol* 24:636-640, 1994.
9. Lee VH, Oh JK, Mulvagh SL, Wijdicks EF: Mechanisms in neurogenic stress cardiomyopathy after aneurysmal subarachnoid hemorrhage. *Neurocrit Care* 5:243-249, 2006.
10. Mayer SA, Lin J, Homma S, Solomon RA, Lenihan L, Sherman D, Fink ME, Beckford A, Klebanoff LM: Myocardial injury and left ventricular performance after subarachnoid hemorrhage. *Stroke* 30:780-786, 1999.
11. Parekh N, Venkatesh B, Cross D, Leditschke A, Atherton J, Miles W, Winning A, Clague A, Rickard C: Cardiac troponin I predicts myocardial dysfunction in aneurysmal subarachnoid hemorrhage. *J Am Coll Cardiol* 36:1328-1335, 2000.
12. Pollick C, Cujec B, Parker S, Tator C: Left ventricular wall motion abnormalities in subarachnoid hemorrhage: an echocardiographic study. *J Am Coll Cardiol* 12:600-605, 1988.
13. Qureshi AI, Sung GY, Razumovsky AY, Lane K, Straw RN, Ulatowski JA: Early identification of patients at risk for symptomatic vasospasm after aneurysmal subarachnoid hemorrhage. *Crit Care Med* 28:984-990, 2000.
14. Tung P, Kopelnik A, Banki N, Ong K, Ko N, Lawton MT, Gress D, Drew B, Foster E, Parmley W, Zaroff J: Predictors of neurocardiogenic injury after subarachnoid hemorrhage. *Stroke* 35:548-551, 2004.

*Citation:* World Neurosurg. (2015) 83, 880-885.  
<http://dx.doi.org/10.1016/j.wneu.2015.01.013>

*Journal homepage:* [www.WORLDNEUROSURGERY.org](http://www.WORLDNEUROSURGERY.org)

*Available online:* [www.sciencedirect.com](http://www.sciencedirect.com)

1878-8750/\$ - see front matter © 2015 Elsevier Inc.  
All rights reserved.

## Call for Neurosurgery and the Arts

*World Neurosurgery* is changing the cover art and filler art motif. This motif involves the display of art by neurosurgeons. Hence, we are seeking art, in any visual form, for this endeavor on an ongoing basis. Such art might naturally include photography, photographs of sculptures or paintings, prose or poetry, etc. We ask Neurosurgeons to submit high resolution images of such art. These images will be considered for future *World Neurosurgery* journal covers and for filler art. When submitting your images, please include a brief description. These can be submitted directly to [moorec2@ccf.org](mailto:moorec2@ccf.org).