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ORIGINAL ARTICLE

Ventricular Arrhythmia Risk After Subarachnoid Hemorrhage

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Abstract
Introduction Cardiac morbidity and mortality after aneurysmal subarachnoid hemorrhage (SAH) are attributable to myocardial injury, decreased ventricular function, and ventricular arrhythmia (VA). Our objective was to test the relationships between QTc prolongation, VA, and survival after SAH.
Methods In 200 subjects with acute aneurysmal SAH, electrocardiograms, echocardiograms, and telemetry were evaluated. Serum electrolytes and troponin were also evaluated.
Results Initial QTc (mean 460 ± 45 ms) was prolonged (≥470 ms) in 38% of subjects and decreased on follow-up (469 ± 49 initial vs. 435 ± 31 ms follow-up; $N = 89$; $P < 0.0001$). VA was present in 14% of subjects, 52% of subjects with VA had QTc ≥ 470 ms, and initial QTc trended toward longer duration in subjects with VA (474 ± 61 vs. 457 ± 42 ms; $P = 0.084$). Multivariate analysis demonstrated significant predictors of VA after SAH were increasing age (OR 1.3/5 years; $P = 0.025$), increasing stroke severity (OR 1.8; $P = 0.009$), decreasing heart rate (OR 0.5/10 beats/min; $P = 0.006$), and the absence of angiotensin converting enzyme inhibitor or angiotensin II receptor antagonist use at SAH onset (OR 0.10; $P = 0.027$). All-cause mortality was 19% (25/135) at 3 months and subjects with VA had significantly higher mortality than those without VA (37% vs. 16%; $P = 0.027$).
Conclusions These data demonstrate that QTc prolongation and arrhythmias are frequently noted after SAH, but arrhythmias are often not associated with QTc prolongation. In addition, the presence of VA identified subjects at greater risk of mortality following their SAH.

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Keywords Ventricular arrhythmia · Subarachnoid hemorrhage · Gender · QTc prolongation

Abbreviations

SAH	Subarachnoid hemorrhage
EF	Ejection fraction
VA	Ventricular arrhythmia
ECG	Electrocardiogram

Introduction

Subarachnoid hemorrhage (SAH) accounts for only ~3% of all strokes, yet it accounts for 27% of years of life lost to strokes before age 65 [1]. Cardiac conduction and rhythm disturbances are common after aneurysmal SAH, with the prevalence of QTc interval prolongation being 40–70% [2–6] and prevalence of arrhythmia being 15–41% [2, 5]. Traumatic SAH is also associated with QTc prolongation, suggesting QTc prolongation is less likely due to factors that caused the SAH and more likely a consequence of the SAH itself [7]. QTc prolongation causes arrhythmias and sudden cardiac death and is seen in long QT syndrome and is associated with sudden death in heart failure [8, 9]. Given that QTc prolongation is associated with SAH and that SAH is frequently associated with arrhythmia, we hypothesized that QTc prolongation would be an independent predictor of VA after aneurysmal SAH and that the presence of QTc prolongation and/or VA would correlate with survival after SAH.

Materials and Methods

Clinical Subjects

A total of 200 adult subjects with acute, aneurysmal SAH were prospectively evaluated in the Subarachnoid Hemorrhage and Myocardial Infarction and Ischemia (SAHMII) study, as approved by the local Institutional Review Board. Entry criteria for SAH severity was a Hunt and Hess Grade $\geq$ 3 and/or a Fisher Grade $\geq$ 2, as determined by the attending neurosurgeon. Aneurysm rupture was diagnosed using digital subtraction angiography or CT angiography. Subjects with traumatic SAH or pre-existing neurological disease were not enrolled. Once the subjects or their proxies provided informed consent, the subjects were enrolled irrespective of race or ethnicity.

All subjects were managed according to institutional guidelines based on national standards. Routine care included prophylactic nimodipine, intravenous magnesium, and blood pressure control with either antihypertensives (labetolol, nitroprusside, or nicardipine) or vasopressor/inotrope therapy (phenylephrine, norepinephrine, dopamine, or dobutamine). Death for any reason from hospital admission to 3 months from the time of the SAH (i.e., 3-months, all-cause mortality) was determined from the medical record or post-discharge follow-up at 3 months by family interview.

Demographic Characteristics

Demographic characteristics were recorded on enrollment and were verified by reviewing the electronic medical record, which included referring hospital and emergency medical service records if applicable (AccessAnywhere; Ontario, Canada). A complete past medical history was similarly recorded and included the presence of heart disease (i.e., myocardial infarction, coronary atherosclerosis, cardiomyopathy, and moderate/severe valvular dysfunction) and heart disease risk factors including hypertension, hyperlipidemia, and diabetes.

Medications

Home and in-hospital medication administration was determined by reviewing the electronic medical record. As a surrogate measure of medications circulating at the time of aneurysm rupture, home medications were recorded, including antiarrhythmic agents (e.g., β-blockers), angiotensin converting enzyme inhibitors (ACEi), angiotensin II receptor blockers (ARB), HMG-CoA reductase inhibitors ("statins"), and calcium channel blockers. The in-hospital administration of vasopressors and inotropes was also recorded. One subject's records documented an unknown medicine for hypertension without details and she passed away from her SAH, so comparisons regarding antihypertensive medications involve 199 subjects.

Holters, Electrocardiograms, and Echocardiograms

Twelve-lead electrocardiograms (ECGs) were obtained on admission ($N = 200$) and repeated $\geq$7 days later if subjects remained hospitalized ($N = 89$). Manual ECG analysis consisted of measuring RR, PR, QRS, and QT intervals by averaging 3 beats, excluding U-waves from QT intervals. Maximal measurements were typically obtained from a single lateral chest lead (e.g., V5), but were rarely obtained from a single limb lead (e.g., II) due to longer interval duration. Most ECG's were digital recordings transmitted directly from the ECG machines, while <1% were scanned ECG printouts from outside hospitals, with measurements obtained using Cardio Calipers v3.3 (Iconico, Inc; New York City, NY). QTc intervals, or QT interval durations corrected for heart rate,

were calculated using the Bazett [10], Fridericia [11], and Framingham [12] corrections. Intervals were averaged over 5 beats in the setting of atrial arrhythmias. A prolonged QTc was defined as ≥470 ms (Bazett correction).

Holter monitoring was initiated upon enrollment, with a recording duration goal of ≥48 h. Holter monitoring was performed to identify VA, defined as non-sustained ventricular tachycardia (NSVT; ≥3 beats), ventricular tachycardia (VT; ≥10 s), ventricular fibrillation (VF), and *torsades de pointes*.

Two-dimensional echocardiography was performed within 72 h of SAH onset (Vivid 7 GE-Vingmed, Horten, Norway) in a subset of patients ($N = 117$) and repeated 5–7 days later if still hospitalized ($N = 97$). Left ventricular ejection fraction (EF) was assessed using the biplane Simpson's rule, with normal ≥50% [13].

Serum Electrolytes and Troponin I

Serum was collected at least daily during the initial 5 days after enrollment and was analyzed for initial potassium (3.5–5.1 mmol/l), initial magnesium (0.65–1.05 mmol/l), and peak troponin levels, with a troponin elevation defined as ≥0.30 μg/l according to institutional criteria.

Statistical Analysis

In univariate analyses, we compared demographic characteristics, past medical history, medications, ECG characteristics, laboratory values, and echocardiogram parameters between subjects with and without incident VA. Continuous variables displayed a normal distribution and were compared by ANOVA. Categorical variables were compared by χ^2-analyses. Changes in EF and ECG characteristics were evaluated by paired *t* tests. Variables that differed by QTc prolongation ($P \leq 0.10$) or resulted in >10% change in the parameter of interest from univariate estimates were included in multivariable models using binomial regression with significance of $P \leq 0.05$ [14]. The multivariate models evaluating VA employed forward logistic regression, with QTc duration being the last variable entered (SPSS v15.0; Chicago, SPSS, Inc.).

Results

Population Characteristics

For the 200 subjects enrolled, 27 had ventricular arrhythmia (VA). The population characteristics with respect to the absence or presence of VA are shown in Table 1. Subjects with VA were significantly older than those without (59 ± 11 vs. 54 ± 10 years; $P = 0.031$). There were no significant differences in VA prevalence by gender or race. Stroke severity when assessed by mean Hunt and Hess Grade was significantly higher in those with VA (3.2 ± 1.2 vs. 2.7 ± 1.0; $P = 0.040$), but was not significantly higher in those with VA when assessed by mean Fisher Grade (3.1 ± 0.7 vs. 2.8 ± 0.7; $P = 0.109$).

A history of heart disease was not associated with VA (Table 1) and subjects with VA were significantly less likely to have a history of hypertension ($P = 0.035$) or hyperlipidemia ($P = 0.026$). The prevalence of VA was significantly reduced in subjects who were taking either an ACEi or ARB at SAH onset (3% vs. 16%, $P = 0.042$), and administration of statins trended toward being less common in those with VA ($P = 0.069$). The prevalence of VA was unrelated to home β-blocker use ($P = 0.438$), as well as being unrelated to home use of calcium channel blockers, vasodilators, and diuretics (data not shown). Excluding β-blockers, no subject was taking an antiarrhythmic agent at SAH onset. Finally, the in-hospital administration of vasopressors and/or inotropes was unrelated to VA development (data not shown).

Holter Monitoring, Electrocardiograms, and Echocardiograms

The average Holter recording duration was 62 ± 26 h. Of the 27 subjects who developed VA, 1 had VT lasting 11 s and 1 had VF. Of the remaining 25 subjects with NSVT, VT run length ranged from 3 to 11 beats (median = 4) and total VT beats ranged from 3 to 115 (median = 5). No subject demonstrated *torsades de pointes*. Mean heart rate during Holter monitoring was significantly lower in those with VA (77 ± 8 vs. 82 ± 12 beats/min; $P = 0.033$).

Mean initial QTc for all subjects was 460 ± 45 ms using Bazett correction, 441 ± 44 ms using Fridericia correction, and 438 ± 41 ms using Framingham correction. No subject had a bundle branch block on enrollment (mean initial QRS 83 ± 12 ms) and the QRS duration was significantly longer in the initial ECG compared to the follow-up ECG (83 ± 13 vs. 78 ± 13 ms; $N = 89$; $P = 0.0004$). The QTc duration was significantly longer on the initial ECG compared to the follow-up ECG, regardless of the correction algorithm used (e.g., Bazett 469 ± 49 vs. 435 ± 31 ms; $N = 89$; $P < 0.0001$). Initial QTc duration trended toward being significantly longer in those with VA when using Bazett and Framingham corrections (474 ± 61 vs. 457 ± 42 ms; $P = 0.084$ and 453 ± 54 vs. 436 ± 38 ms; $P = 0.052$, respectively), and was significantly longer using the Fridericia correction (456 ± 57 vs. 438 ± 41 ms; $P = 0.049$).

Initial EF was <50% in 18/117 subjects (15%), and EF was <50% in 9/97 subjects (9%) at follow-up. No subject was diagnosed with a cardiomyopathy prior to their SAH.

Table 1 Baseline demographics and associations with VA

	Total	−VA	+VA	*P*-value
Total population [*N*]	200	173	27	–
Age (years ± SD)	55 ± 10	54 ± 10	59 ± 11	0.031
Gender (% women)	71%	71%	70%	0.987
Race (% Af-Am)	10%	9%	11%	0.759
Hunt and Hess Grade (mean ± SD)	2.8 ± 1.1	2.7 ± 1.0	3.2 ± 1.2	0.040
Fisher Grade (mean ± SD)	2.9 ± 0.7	2.8 ± 0.7	3.1 ± 0.7	0.109
Past medical history				
Cardiac	7%	6%	11%	0.296
Hypertension	49%	51%	30%	0.035
Hyperlipidemia	20%	22%	4%	0.026
Home medications				
β-Blockers [$N = 199$]	11%	10%	15%	0.438
ACEi/ARB [$N = 199$]	18%	20%	4%	0.042
Statins	16%	17%	4%	0.069
Initial ECG intervals (ms ± SD)				
PR	151 ± 25	152 ± 25	149 ± 24	0.539
QRS	83 ± 12	83 ± 12	82 ± 12	0.619
QT	407 ± 52	404 ± 50	424 ± 59	0.063
QTc (Bazett)	460 ± 45	457 ± 42	474 ± 61	0.084
QTc (Bazett) ≥ 470 ms (%)	38%	35%	52%	0.098
Holter monitoring				
Mean heart rate	82 ± 12	82 ± 12	77 ± 8	0.033
Hospital medications				
Vasopressors	27%	27%	22%	0.588
Inotropes	24%	24%	22%	0.866
Serum laboratories				
Troponin > 0.3 μg/l	31%	28%	52%	0.012
Initial potassium (mmol/l)	3.7 ± 0.5	3.7 ± 0.5	3.8 ± 0.5	0.184
Initial magnesium (mmol/l)	1.6 ± 0.3	1.6 ± 0.3	1.6 ± 0.4	0.699
Echocardiogram [*N*]	116	81	35	–
Initial EF < 50%	15%	13%	29%	0.116

Af-Am African-American; *ACEi* angiotensin converting enzyme inhibitor; *ARB* angiotensin II receptor blocker; *statin* HMG-CoA reductase inhibitor; *EF* ejection fraction; *ms* milliseconds; *SD* standard deviation

There was no significant change in EF between initial (60 ± 10%) and follow-up evaluations (60 ± 8%; $N = 97$; $P = 0.757$). Subjects with VA were somewhat more likely to have an EF <50% than those without VA, but this association failed to reach significance (29% vs. 13%; $P = 0.116$).

Serum Troponin and Electrolytes

Peak troponin elevation ≥0.3 μg/l was present in 62 subjects (31%) and initial QTc was longer in those with a peak troponin ≥0.3 μg/l (480 ± 50 vs. 450 ± 40 ms; $P < 0.0001$). While potassium on admission was significantly lower in those with a prolonged initial QTc (≥470 ms; 3.6 ± 0.5 vs. 3.8 ± 0.5 mmol/l; $P = 0.028$), serum magnesium was unrelated to QTc (data not shown). Peak troponin ≥0.3 μg/l was significantly associated with developing VA (52% vs. 28%; $P = 0.012$). Initial potassium and magnesium levels were unrelated to VA.

Stroke Severity

Subjects with a peak troponin ≥0.3 μg/l had a higher, more severe SAH grade than those with a troponin <0.3 μg/l, regardless if using mean Hunt and Hess Grade (3.2 ± 1.1 [$N = 62$] vs. 2.6 ± 1.0 [$N = 138$]; $P < 0.001$) or mean Fisher Grade (3.1 ± 0.6 [$N = 62$] vs. 2.8 ± 0.7 [$N = 138$]; $P = 0.005$). Subjects with a prolonged initial QTc ≥470 ms trended toward a higher SAH severity than those with QTc <470 ms if using mean Hunt and Hess

Grade (2.9 ± 1.1 [$N = 75$] vs. 2.7 ± 1.0 [$N = 125$]; $P = 0.072$), but not mean Fisher Grade (3.0 ± 0.7 [$N = 75$] vs. 2.8 ± 0.7 [$N = 125$]; $P = 0.259$).

Multivariate Analysis of Ventricular Arrhythmia

When considering the total population of 200 subjects, logistic regression analysis of the odds of incident VA (Table 2) indicated that multiple factors significantly contributed in increased odds of VA, including increasing age (OR 1.3 per 5 years; $P = 0.025$), increasing Hunt and Hess stroke severity (OR 1.8; $P = 0.009$), lower heart rate (OR 0.5 per 10 beats/min; $P = 0.006$), and not taking an ACEi/ARB at SAH onset (OR 0.10; $P = 0.027$). QTc prolongation ≥470 ms was not a significant predictor of VA (OR 1.9; $P = 0.155$), however, the odds ratio was only slightly reduced (univariate OR 2.0).

Gender

We observed a gender disparity of SAH in our study (71% women), which is the proportion typically presented in the literature [15, 16]. Given this disparity, we sought potential cardiovascular responses to SAH that varied by gender. Initial QRS duration was significantly shorter in women than men (81 ± 12 vs. 87 ± 10 ms; $P = 0.003$) and remained shorter in women on follow-up (76 ± 13 vs. 82 ± 12 ms; $N = 89$; $P = 0.023$). In contrast, initial QTc duration trended toward being longer in women than men (463 ± 46 vs. 451 ± 43 ms; $P = 0.078$), and the difference between initial and follow-up ECG remained significant, regardless of gender (women [$N = 59$]: 475 ± 50 vs. 438 ± 28 ms; $P < 0.0001$; men [$N = 30$]: 458 ± 45 vs. 429 ± 37 ms; $P = 0.001$). There was a trend toward women being more likely to have an initial EF <50% (19% [$N = 82$] women vs. 6% [$N = 35$] men; $P = 0.073$). In women, initial QTc duration trended toward being longer in those with VA compared to those without VA (482 ± 66 [$N = 19$] vs. 460 ± 42 ms [$N = 122$]; $P = 0.062$). However, initial QTc duration was similar in males with VA compared to those without VA (455 ± 48 [$N = 8$] vs. 450 ± 42 ms [$N = 51$]; $P = 0.778$). The prevalence of VA was similar between women and men (13% vs. 14%; $P = 0.987$).

Table 2 Logistic regression analysis of ventricular arrhythmia

($N = 199$)[a]		95% CI		
	OR	Lower	Upper	*P*-value
Age (5 years)	1.3	1.0	1.6	0.025
Hunt and Hess	1.8	1.2	2.9	0.009
Heart rate (10 bpm)	0.5	0.3	0.8	0.006
ACEi/ARB home medication	0.1	0.1	0.8	0.027
QTc ≥ 470 ms	1.9	0.8	4.8	0.155

[a] one subject passed away from SAH and antihypertensive medication could not be verified. (*ACEi/ARB* angiotensin converting enzyme inhibitor or angiotensin receptor blocker)

Association between Arrhythmia and All-Cause Mortality

All-cause mortality was 19% (25/135) at 3 months. Subjects with QTc prolongation had a higher mortality than those without QTc prolongation, although the difference was not significant (24% vs. 15%; $P = 0.175$). Subjects with VA had significantly higher mortality than those without VA (37% vs. 16%; $P = 0.027$).

Discussion

Our data demonstrate significant predictors of VA following aneurysmal SAH include increasing age, increasing stroke severity, and decreasing heart rate. Also, the home medication regimens that include ACEi/ARB at SAH onset may provide a modest protection from VA. While QTc interval prolongation only demonstrated a trend toward being associated with VA, the univariate odds ratio and multivariate odds ratios were nearly identical (univariate OR 2.0 vs. multivariate OR 1.9), suggesting monitoring QTc interval duration is not without merit when monitoring for VA. Finally, our data also demonstrate a significant association between VA and increased all-cause mortality, even when that VA is only short bursts of non-sustained ventricular tachycardia.

Our data demonstrate a QTc interval prolongation prevalence of 38% and a VA prevalence of 14%, which is in-line with previous studies of QTc interval prolongation prevalence being 40–70% [2–6] and prevalence of arrhythmia being 15–41% [2, 5]. We identified no individual with *torsades de pointes*, which is historically associated with SAH [17, 18]. However, an extensive literature review including over 1,100 patients who suffered a SAH demonstrated only cases of *torsades de pointes*, which could be explained by more common causes, such as hypokalemia or medications [19]. Consequently, it is not surprising that we did not detect *torsades de pointe* in this study.

A catecholamine surge is frequently suggested as promoting cardiac mortality after SAH, possibly by directly promoting QTc prolongation and/or VA [20, 21]. Similarly, the catecholamine surge has been associated with an increased prevalence of ventricular ectopy [22, 23]. The potential role of catecholamine stimulation following SAH is consistent with prior studies which demonstrated

decreased cardiac injury and fewer ECG changes upon administration of β-blockers [24, 25]. Given the regional variability of sympathetic innervation and the potential for spatial heterogeneities in adrenergic receptors in the heart, adrenergic stimulation can promote dispersion of repolarization, prolonged QTc, and VA [26, 27]. While other downstream effects of the catecholamine surge may also contribute to VA, the catecholamine surge may be a direct trigger of VA. Interestingly, we demonstrated both a lengthening of the QRS interval and QTc prolongation, suggesting generalized electrophysiological abnormalities following the SAH affecting both conduction and repolarization.

Gender-specific variations in myocardial repolarization have been observed for decades in humans, consistently demonstrating adult women have longer QTc durations than men [28]. Our study suggested initial QTc duration only trended toward being longer in women than men, although the QTc duration would likely have been significantly longer in women if QRS durations were not significantly shorter in women. Investigation into the etiology of differences in QTc duration by gender has suggested the difference is not a lengthening of the QTc in women but is actually a shortening of the QTc duration in men following puberty [29]. The longer QTc duration in women has clinical ramifications, as seen in the long QT syndrome where women experience more serious VA, morbidity, and mortality than men [30, 31]. Importantly, animal studies have demonstrated there are gender-based regional variations in ion channel currents and that gonadal steroids directly modify ion channel currents [32–34].

Hypokalemia and hypomagnesemia may also contribute to QTc interval prolongation and VA following SAH [3, 35, 36]. Hypokalemia and hypomagnesemia have been documented following SAH, as well as hypokalemia following direct epinephrine infusion [4]. Our study documented hypokalemia (32% prevalence) and hypomagnesemia (11% prevalence), but only found an association between hypokalemia and QTc interval prolongation. Neither hypokalemia nor hypomagnesemia were associated with VA.

Myocardial injury and ventricular dysfunction are classic causes of VA and sudden death, typically associated with coronary artery disease-induced ischemia [37, 38]. Myocardial injury and ventricular dysfunction are seen following SAH, although usually without coronary artery disease [39–41]. Although our data suggest neither myocardial injury nor ventricular dysfunction are independent predictors of VA after multivariate analysis, which controlled for potential confounders, our univariate analyses support a contributing role for myocardial injury in VA risk following SAH.

We demonstrated increasing age is significantly associated with the development of VA following SAH, as has been reported previously [42]. Increasing Hunt and Hess Grade was associated with VA in univariate ($P = 0.04$) and multivariate ($P = 0.024$) analyses. The association of decreasing heart rate with increased risk of developing VA may be due to increasing vagal reflex, which is postulated to follow the initial catecholamine surge [22].

Interestingly, only one subject taking an ACEi/ARB at SAH onset developed VA (ACEi/ARB = 1/35 [3%] vs. no ACEi/ARB = 26/164 [16%]; $P = 0.042$). Increasing evidence suggests inhibition of the renin-angiotensin system acts as a sympathetic antagonist [43, 44]. One proposed mechanism invokes angiotensin II as a sympathetic agonist requiring oxidative stress and decreased nitrous oxide [45, 46]. Decreased VAs in those on an ACEi/ARB has been described previously, however, not all studies have shown a benefit and data have not been reported for SAH [47–51].

The arrhythmias identified in this study were predominantly NSVT and no patient developed *torsades de pointes*. This is most likely due to the overall population being relatively healthy, with only 7% having significant heart disease. However, substantial evidence exists, which supports the predictive value of VA with regard to sudden cardiac death in patients with structural heart disease [52–54]. Furthermore, the utility of identifying VA following SAH is supported by the finding of increased all-cause mortality at 3 months in those with VA.

There were limitations to our study. Echocardiographic and outcome data were only available for a subset of subjects. Our study essentially confined arrhythmia monitoring to the initial 3 days following enrollment, owing to the fact that protracted hospitalizations could contribute numerous confounding factors. Given that QTc data were not obtained continuously, the true QTc peak could have been missed. Similarly, VA monitoring was only performed during the initial hospitalization. Consequently, patients could have had significant arrhythmias follow the removal of the Holter monitors. Our findings must be verified in a larger study population with wider racial/ethnic diversity. While dichotomizing QTc interval duration at 470 ms is traditional, it belies the fact that women's QTc interval durations on average are longer than men's. In light of this, we reviewed the primary outcomes of our study by either dichotomizing with QTc interval duration prolongation being $\geq$470 ms for women and $\geq$450 ms for men or by binning QTc duration into 10 ms intervals. Neither of these manipulations resulted in significantly different study outcomes (data not shown). Finally, while the acute management of an aneurysmal SAH involves complex interactions both within and between multiple organ systems, some of which can independently contribute to QTc interval abnormalities and/or VAs, our study

focused on initial presentation variables to identify predictors of adverse outcomes including VA following SAHs. We attempted to account for inherent variability by evaluating a relatively large population following SAH. We also recognize that patients can have unpredictable courses and that the peak QTc and/or arrhythmias could occur either prior to admission or several days following the initial ECG, at the time of subsequent complications such as vasospasm.

Conclusions

In 200 subjects with SAH, older age, a slower heart rate, an absence of ACEi/ARB therapy at SAH onset, and worse stroke severity are associated with developing VA following SAH. A protective benefit of ACEi/ARB therapy was suggested by our work which, while not entirely novel, has not been reported in conjunction with SAHs and will require further study. Although QTc prolongation may play a role in arrhythmia risk after SAH, other factors related to stroke severity and the putative catecholamine surge appear to be important. The lack of a clear association between QTc prolongation and VA raises the possibility that other factors associated with the catecholamine surge cause VA and increase mortality. Finally, while QTc interval prolongation and *torsades de pointes* are classically associated with SAH, we found no subject with *torsades de pointes*, bringing into question traditional teachings in medicine.

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