Role of bioclimate conditions on cerebral aneurysm rupture in the Brittany region of France

Y. Launey, G. Le Gac, P.-J. Le Reste, Jean-Yves Gauvrit, X. Morandi, P. Seguin

Version of Record: https://www.sciencedirect.com/science/article/pii/S0028377019302966
Manuscript_6e01dfe857b620a890df8c3a3d6ed165

Title page

Title: Role of bioclimate conditions on cerebral aneurysm rupture in the Brittany region of France

Yoann LAUNEY, MD, PhD[a], Grégoire LE GAC, MD[a], Pierre-Jean LE RESTE, MD[b], Jean-Yves GAUVRIT, MD, PhD[c], Xavier MORANDI, MD, PhD[b], Philippe SEGUIN, MD, PhD[a].

[a] Critical Care Unit, Department of Anesthesiology and Critical Care Medicine, Rennes University Hospital, 2 Rue Henri Le Guilloux, 35033 Rennes, France

[b] Department of Neurosurgery, Rennes University Hospital, 2 Rue Henri Le Guilloux, 35033 Rennes, France

[c] Department of Neuroradiology, Rennes University Hospital, 2 Rue Henri Le Guilloux, 35033 Rennes, France

Corresponding author: Dr Yoann Launey, Critical Care Unit, Department of Anesthesiology and Critical Care Medicine, Rennes University Hospital, 2 Rue Henri Le Guilloux, 35033 Rennes, France. Email: yoann.launey@chu-rennes.fr

Authorship

Conception and design of the study: YL, GL, PJL. Acquisition of data: GL. Analysis and interpretation of data: YL, GL, PJL, PS. Drafting the article or revising it critically for important intellectual content: JYG, XM, PS. Final approval of the version to be submitted: YL, PS.

Financial support: None

Conflict-of-interest statement: None

Manuscript word count: 4,394

Abstract word count: 213

References count: 48

Role of bioclimate conditions on cerebral aneurysm rupture in the Brittany region of France

Abstract

Introduction: Subarachnoid hemorrhage (SAH) from intracranial aneurysm rupture is an unpredictable event responsible for significant morbidity and mortality. Despite inconsistencies, some studies suggest a potential role of climate conditions in SAH onset. The purpose of this study was to determine the impact of climatic and lunar factors on onset of SAH in an oceanic climate such as that of Brittany, France.

Methods: All adults with SAH admitted to the neurosurgery department and intensive care unit of the University Hospital of Rennes (France) between January 1st, 2011 and December 31st, 2012 were included. Meteorological variables, their variations, lunar phases and tidal coefficients were compared between days with and without SAH.

Results: We retrospectively included 295 patients with SAH. Mean minimum temperature was significantly lower during days with SAH (7.7±4.7°C *versus* 8.3±4.6°C; $p = 0.039$); temperature variation between 2 successive days was significantly greater for days with SAH (8.6±4.1°C *versus* 7.9±3.8°C; $p < 0.01$). Multivariate analysis showed that a 2-day temperature drop greater than or equal to 8°C was associated with 35% increased risk of SAH (odds ratio 1.35 [1.03 – 1.77]). There were no significant effects of other meteorological variables, lunar phase or tidal coefficient on SAH occurrence.

Conclusion: Low temperature and sudden temperature drop were associated with increased occurrence of SAH in Brittany, France.

Keywords

Subarachnoid hemorrhage; cerebral aneurysm; climate conditions; meteorological variables

Introduction

Aneurysmal subarachnoid hemorrhage (SAH) is a common pathology, with incidence ranging from 6 to 20 per 100,000, and is responsible for significant morbidity and mortality [1–5]. Several individual risk factors for aneurysm rupture are well-known, such as female gender, age >50 years, alcohol consumption, smoking and hypertension [6,7]. However, onset of aneurysmal SAH is unpredictable, often described as "a bolt from the blue". Some studies suggested that climate or the Moon may influence humans and animals and the occurrence of various diseases [8–10]. A prospective study suggested that atmospheric pressure positively impacts absolute intracranial pressure in humans [11]. More specifically, some authors suggested a role of climate conditions in intracerebral hemorrhage and SAH [12–18], but reported conflicting results. Some found an association between onset of SAH and atmospheric pressure changes [18,19], or the season and low temperature [14], while other studies found no association between these diseases and climatic conditions [13,20–22]. To explain these inconsistencies, we hypothesized that geographic location had an impact on aneurysm rupture according to the type of climate. In geographic regions without significant meteorological variations, or in large enough regions subject to various climate types, several studies showed no association between SAH onset and climatic conditions [13,22]. Moreover, statistical tools and analysis differed, and studies mainly analyzed climate data as isolated variables without considering them as closely intertwined values composing a climate profile. Similarly, it has been suggested that the phases of the Moon influence SAH onset. The New Moon phase seems to be associated with increased SAH onset [23], but studies investigating the role of the Moon are scarce and reported inconsistent results [21,24]. Moreover, these studies considered only illumination phase and not the interaction between Moon phase and tidal coefficient.

The purpose of this study was to determine the impact of climatic factors and the Moon on new onset of SAH in a region with oceanic climate (Brittany, France).

Material and methods

A retrospective study was conducted in Rennes University Hospital, a tertiary hospital managing most cases of SAH in Brittany. Brittany is a French region with 3.26 million inhabitants in 2012. It has an area of 27,208km²; the climate is temperate oceanic, influenced by 2 seas (the Channel and the Atlantic Ocean) [25]. Rennes and Brest are the two main cities in Brittany, with 318,127 and 314,844 inhabitants in 2012 respectively. Patients initially admitted to Brest hospital and secondly transferred to Rennes for coiling were also included. The study was submitted to the local review board of Rennes University Hospital, which judged that patient consent was not required under French law.

Objectives

The primary objective of this study was to determine whether atmospheric pressure variation influenced new onset of SAH on global analysis of the weather in Rennes and Brest, comparing days with or without SAH onset.

Secondary objectives were to identify other climatic factors (temperature, humidity, wind speed) potentially responsible for SAH onset on global analysis, to determine impact on SAH severity according to the WFNS (World Federation of Neurological Societies) scale, and aneurysm location and size based on individual data analysis. Finally, the influence of the Moon and the related tidal coefficient was studied.

Patient Data

All adult patients (>18 years) with aneurysm or spontaneous non-aneurysmal SAH admitted to the neurosurgery department and intensive care unit of the Rennes University Hospital between January 1st, 2011 and December 31st, 2012 were included. Patients with SAH due to trauma, ruptured arteriovenous malformations, vasculitis or other structural lesions were excluded. Patient data comprised age, gender, known SAH risk factors (hypertension, smoking and alcohol consumption), geographical location and date of SAH onset (defined as date of onset of headache or of admission in case of coma), hospital stay, and mortality. General and SAH-specific severity scores were calculated: Glasgow Coma Score, Simplified Acute Physiology Score II (SAPS II) [26], Fisher score and World Federation of Neurosurgical Societies (WFNS) score. Cerebral aneurysm was characterized by location according to 6 regions (anterior, medium, posterior, vertebrobasilar, carotid, or *sine materia* if no aneurysm were visualized on cerebral CT-scan). Aneurysm size in millimeters, type of aneurysm treatment (surgical clipping, coiling or abstention), and complications (intracranial pressure, re-bleeding, cerebral vasospasm) were reported.

Meteorological data

For individual analysis, the season, the maximum, minimum and change in barometric pressure, relative humidity and air temperature, maximum and average wind speed during the day of SAH onset and the day before were collected from the regional climate website "http://www.meteo-bretagne.fr". If data were not available for the exact geographical area of the SAH occurrence, data from the closest area were used.

For global analyses, the maximum and minimum values and variation (defined as maximum minus minimum value over 24h) were used for the following parameters: barometric pressure, relative humidity and air temperature. For each day, the maximum and average wind speed in Rennes and Brest during the study period were collected.

Moon and tide data

Since the tidal coefficient is representative of the global effect of the Moon on the Earth, including oceans, land masses and atmosphere, we considered variations in tidal coefficient to be negligible at the scale of Brittany. Each day was matched with the corresponding Moon phase and tidal coefficient of the nearest harbor (e.g., Saint-Malo harbor for the Rennes region, representing the influence of the Channel, and Brest harbor for the Brest region and southern Brittany under the influence of the Atlantic Ocean). All data were extracted from the website "http://maree.info". A lunar cycle lasts 29.5 days, corresponding to one complete revolution of the Moon around the Earth, and is divided into 8 phases (New Moon; Waxing Crescent; First Quarter; Waxing Gibbous; Full Moon; Waning Gibbous; Last Quarter; Waning Crescent). Tidal coefficients were collected twice a day, in the morning and in the afternoon, then the maximum of the 2 values was classified in 9 categories (≤39; 40 – 49; 50 – 59; 60 – 69; 70 – 79; 80 – 89; 90 – 99; 100 – 109; ≥110).

Statistical analysis

Statistical analysis was performed with SAS software version 9.4. T-tests were used for quantitative climatic variables (air temperature, barometric pressure, relative humidity, mean and maximum wind speed, and their variations. Climatic variation was defined by a rise or fall in a climatic variable over 2 successive days, calculated as the maximum for one day minus the minimum for the day before, a rise having a positive value and a drop a negative value.

Qualitative variables (lunar phase, tidal coefficient, patient characteristics) were analyzed using chi-square test. Multiclass variables were analyzed by ANOVA and results expressed as odds ratio (OR) and 95% confidence interval (95%CI). Tidal coefficients were analyzed as a quantitative and as a qualitative variable after allocation to categories. Multivariate analysis and ROC curves were built from the logistic model to determine the most relevant variable and a threshold for SAH risk. Multivariate analysis by ANOVA and logistic regression determined whether climate variations influenced SAH severity, assessed on WFNS score. The secondary objective was to determine the effect of climate on aneurysm location. Variables influencing the size of ruptured aneurysms were analyzed by a generalized linear model. A p-value <0.05 was considered statistically significant.

Results

Patient characteristics

We retrospectively included 295 patients from Rennes and Brest, admitted for SAH. Patient characteristics and SAH risk factors are summarized in Table 1 and severity scores associated with stratified mortality in Table 2. Mean age was 53±13 years, with a female rate of 0.64. Overall mortality was 8%, the mean ICU stay 7.7±8.2 days, and hospital stay 22.7 ±24.9 days.

Aneurysm characteristics

Aneurysm locations were mostly in the anterior (anterior communicating artery; anterior cerebral artery: 34%) and middle cerebral network (middle cerebral artery: 22%). Mean aneurysm size was 5.8±3.2 mm. Most intracranial aneurysms were managed by interventional radiological coiling, and the others by surveillance or surgical clipping (Table 3).

Monthly and seasonal SAH incidence

SAH occurred on 259 (26%) of the 731 screened days. The highest rates were in July (n = 29 days; 47%) and January (n = 28 days; 45%) (Figure 1), and the lowest rates in May and August (n = 16; 26%) (Figure 1). Winter was the season with the highest rate (n = 80; 27%)

while Spring had the lowest rate (n = 65; 23%). However, no significant statistical differences in SAH occurrence were found between months (p = 0.26) or seasons (p = 0.54).

Global analysis

Minimum temperature was significantly lower on days with than days without SAH (7.7±4.7°C versus 8.3±4.7°C; p <0.04). There were no significant differences between days with and without SAH for maximum temperature, maximum and minimum barometric pressure, relative humidity, or average or maximum wind speed (Table 4). Two-day temperature drop was significantly greater for days with than without SAH (8.6±4.1°C versus 7.9±3.8°C, p <0.01). No significant differences between days with and without SAH were observed for other climate variations (Table 5).

On multivariate analysis, a 1° drop in temperature increased the risk of aneurysmal SAH by 7% (OR 1.07; 95%IC [1.03-1.10]). The higher the maximum temperature, the lower the risk of SAH (OR 0.97; 95%IC [0.95-0.99]). On ROC curves, for a threshold of 8.0°C, a ≥8.0°C 2-day temperature drop was associated with a 35% increase in SAH risk (OR 1.35; 95%IC [1.03 – 1.77]).

Individual analysis

No influence of climatic variables or their variations on SAH severity was found (Table 6). Variables significantly associated with higher WFNS score comprised: age >50 years (OR 1.90 [1.21 – 2.99]), female gender (OR 2.06 [1.25 – 3.39]) and alcohol consumption (OR 2.41 [1.02 – 5.71]).

No effects of climate variations on SAH onset were observed according to aneurysm location. For aneurysm size, a season-related gradient was observed: 5.9±3.7mm in Winter, 5.3±3.8mm in Spring, 4.9±3.3mm in Summer and 4.8±2.9mm in Fall (p<0.01). Interestingly, smoking and diabetes were associated with ruptured aneurysm size, which was larger in smokers (5.7±3.2mm versus 4.9±3.6mm; $p < 0.04$), and smaller in diabetic patients (2.0±2.8mm versus 5.3±3.4mm; $p < 0.04$).

Moon and tide data

There was no evidence of an influence of lunar phase on the SAH onset (p= 0.11) (figure 2). Mean tidal coefficient was similar between days with (70.5 ±19.2) and without SAH (72.2 ±20.8) (p= 0.21), whatever the level of the tidal coefficient (figure 3) (p = 0.12).

Discussion

This study showed that low temperature and sharp drop in temperature over 48 hours was associated with risk of SAH. However, we did not find any associations between SAH onset and other meteorological variables or their variations, although previous studies have suggested some.

Several studies suggested that SAH occurs more frequently in Winter, as we reported [15,19,27], with a nadir in Summer, whereas in the present study the lowest SAH incidence was in Spring. No significant difference in SAH incidence according to month or season was observed, but the peak incidence in Winter could be explained by the influence of air temperature and its variations. Some studies indicate an influence of temperature on SAH occurrence [14,15,28]. For instance, Gill et al., in a cohort of 1,175 adult patients in Maryland, showed that a decrease of 1°F was associated with a 0.6% increase in the risk of SAH [14]. Rivera-Lara et al. also showed that SAH occurred on colder days with maximum temperature less than 70°F (21°C) [15]. The underlying physiological explanation could be an increase in blood pressure involving vasoconstriction, a modification of blood coagulation [29–31], or inflammation. Bakes et al. investigated the role of influenza and cold temperature on the incidence of SAH during Winter and found an increased incidence density ratio of 1.143 (95%CI 1.129-1.157) per 1°C temperature drop [28]. Similarly, cold weather was reported to increase risk of other vascular diseases such as stroke or myocardial infarction [8,30,32,33]. An explanation could be that colder days induced changes in behavior, physical activity, smoking or alcohol consumption that are known risks factors of aneurysmal SAH [10,34] and may increase blood pressure and induce a slight increase in the pressure gradient between the intrasaccular region and cisternal compartment, affecting aneurysm wall tension, although evidence is lacking.

Moreover, a role for other meteorological variables has been suggested. These studies mostly showed that a steep shift in mean barometric pressure greater than 10hPa during the day before SAH onset was associated with a significant risk of SAH [18,19,35]. Interestingly, in a study including 71 SAH patients under oceanic meteorological conditions, Patrice et al. suggested that a decrease in pO2 may be the trigger of SAH during high atmospheric pressure conditions [36]. The present study did not find any role of barometric pressure, but the mean pressure variations were smaller than in the cited studies.

Several studies failed to bring out any link between climate and SAH [13,20,22]. However, some limitations should be underlined. For instance, the day of SAH onset was determined from national hospital databases in which the hospital admission day was assimilated to the day of SAH occurrence; and the effects of microclimates in different zones were not adequately addressed [20,22]. Similarly, climate changes in the study regions were limited, and notably absolute changes in temperature between the day of SAH occurrence and the day before were lower than in the present study, not exceeding 3°C [13]. Because of oceanic influence (westerly wind, release of the heat accumulated by the ocean during Winter, and warm and swift Atlantic currents prolonging of the Gulf Stream), Brittany experiences larger climate variations than, for example, Düsseldorf (Germany) where the continental climate is uninfluenced by the moderating effect of oceans and consequently shows fewer short climate variations [13]. In line with our results, in Netherlands, a country with oceanic climate, Backes et al. found an association of cold temperature and SAH occurrence [28].

As regards the role of aneurysm location, Hughes et al. [37] found that anterior communicating artery aneurysmal SAH peaked in Summer whereas middle cerebral and posterior communicating artery aneurysmal SAH peaked in Spring and Autumn. Although our results differed from these findings, we did find a seasonal influence on aneurysm rupture according to size: the largest aneurysms ruptured during Winter and the smallest during Summer, which may support our results since aneurysm size is a risk factor for rupture [38]. Interestingly, as previously reported, smoking and diabetes seemed to influence aneurysm size [39]. Smoking was associated with larger aneurysm; but no studies clearly showed a role of diabetes in aneurysm size, whereas the present data suggested that diabetes might be associated with smaller aneurysm size.

Finally, the role of the lunar cycle remains unclear. One study reported an increase in SAH occurrence during the New Moon phase, but its design was retrospective with limited sample size [23], whereas, in a larger cohort of 717 patients with SAH, Lahner et al. found no association [24]. In an original strategy, we aimed to explore tidal impact, another aspect of the Moon’s influence on the Earth and climate; the findings, however, were not significant.

Obviously, our study had several limitations due to its retrospective design. Although we identified the place and day of hospital admission, we failed to determine the exact time and location of the SAH onset. In clinical practice, time-stamping aneurysm rupture is tricky because of initial coma or frequent history of headache. We also cannot exclude climate disparities over the Brittany region, as we considered 2 main climate zones with different areas.

Moreover, not all SAH patients from Brest were included. During the study period, the coiling procedure was not available in Brest University Hospital, and patients requiring this treatment were transferred to Rennes University Hospital, while patients with *sine materia* SAH or undergoing surgery were kept in the Brest hospital. 70% of patients admitted to the Rennes hospital underwent coiling; assuming the same proportion in Brest, 29 patients failed to be included.

Variations in SAH incidence between geographical areas are large, ranging from 6/100,000 in Finland to 20/100,000 inhabitants in Japan [5]; intracranial aneurysm incidence in the overall population, however, is unknown. Some subjects develop cerebral aneurysm without any aneurysm rupture throughout their life [40,41]. This could explain the differences between studies. In the present study, SAH incidence was around 7/100,000 person-years, less than in previous reports [5,18,42]. In addition, this incidence may have been slightly overestimated because of the increase in the population of Brittany during the Summer vacation period. Also, mortality was lower than in previous reports, where it was close to 30% [2–5]. More recent studies showed lower mortality associated with SAH, at 25% [43,44]. Supporting our results, in a nationwide American study in which intra-arterial coiling was predominant, mortality was 13% [17], closer to the present findings (8%). Changes in the treatment of SAH (e.g., intra-arterial coiling) and the exclusion of SAH cases dead on arrival could explain these discrepancies.

Conclusion

Low temperature and sudden temperature drop greater than 8°C increased the risk of SAH occurrence by 35% in Brittany, a French region with temperate climate. There was no evidence that the other investigated meteorological variables influenced SAH occurrence. While tidal influence cannot be excluded, the effects of Moon and tide seem to be more myth than reality. Despite the weak influence of climate found in our study, further investigations are needed to fully understand the pathophysiology and real impact of climate on cerebral aneurysm rupture.

Acknowledgments

The authors acknowledge the provision of meteorological data by Mr. Jérôme Dréano, president of the Météo Bretagne association, Saint-Malo, France.

References

[1] Suarez JI, Tarr RW, Selman WR. Aneurysmal subarachnoid hemorrhage. N Engl J Med 2006;354:387–96. doi:10.1056/NEJMra052732.

[2] Mayer SA, Kreiter KT, Copeland D, Bernardini GL, Bates JE, Peery S, et al. Global and domain-specific cognitive impairment and outcome after subarachnoid hemorrhage. Neurology 2002;59:1750–8. doi:10.1212/01.wnl.0000035748.91128.c2.

[3] Hackett ML, Anderson CS. Health outcomes 1 year after subarachnoid hemorrhage: An international population-based study. The Australian Cooperative Research on Subarachnoid Hemorrhage Study Group. Neurology 2000;55:658–62. doi:10.1212/wnl.55.5.658.

[4] de Rooij NK, Linn FHH, van der Plas JA, Algra A, Rinkel GJE. Incidence of subarachnoid haemorrhage: a systematic review with emphasis on region, age, gender and time trends. J Neurol Neurosurg Psychiatry 2007;78:1365–72. doi:10.1136/jnnp.2007.117655.

[5] Macdonald RL, Schweizer TA. Spontaneous subarachnoid haemorrhage. Lancet Lond Engl 2017;389:655–66. doi:10.1016/S0140-6736(16)30668-7.

[6] Brinjikji W, Zhu Y-Q, Lanzino G, Cloft HJ, Murad MH, Wang Z, et al. Risk Factors for Growth of Intracranial Aneurysms: A Systematic Review and Meta-Analysis. AJNR Am J Neuroradiol 2016;37:615–20. doi:10.3174/ajnr.A4575.

[7] Feigin VL, Rinkel GJE, Lawes CMM, Algra A, Bennett DA, van Gijn J, et al. Risk factors for subarachnoid hemorrhage: an updated systematic review of epidemiological studies. Stroke 2005;36:2773–80. doi:10.1161/01.STR.0000190838.02954.e8.

[8] Ishikawa K, Niwa M, Tanaka T. Difference of intensity and disparity in impact of climate on several vascular diseases. Heart Vessels 2012;27:1–9. doi:10.1007/s00380-011-0206-5.

[9] Bhattacharjee C, Bradley P, Smith M, Scally AJ, Wilson BJ. Do animals bite more during a full moon? Retrospective observational analysis. BMJ 2000;321:1559–61. doi:10.1136/bmj.321.7276.1559.

[10] Lavados PM, Olavarría VV, Hoffmeister L. Ambient Temperature and Stroke Risk: Evidence Supporting a Short-Term Effect at a Population Level From Acute Environmental Exposures. Stroke 2018;49:255–61. doi:10.1161/STROKEAHA.117.017838.

[11] Herbowski L. The major influence of the atmosphere on intracranial pressure: an observational study. Int J Biometeorol 2017;61:181–8. doi:10.1007/s00484-016-1202-3.

[12] Miranpuri AS, Aktüre E, Baggott CD, Miranpuri A, Uluç K, Güneş VE, et al. Demographic, circadian, and climatic factors in non-aneurysmal versus aneursymal subarachnoid hemorrhage. Clin Neurol Neurosurg 2013;115:298–303. doi:10.1016/j.clineuro.2012.05.039.

[13] Beseoglu K, Hänggi D, Stummer W, Steiger H-J. Dependence of subarachnoid hemorrhage on climate conditions: a systematic meteorological analysis from the dusseldorf metropolitan area. Neurosurgery 2008;62:1033–8; discussion 1038-1039. doi:10.1227/01.neu.0000325864.91584.c7.

[14] Gill RS, Hambridge HL, Schneider EB, Hanff T, Tamargo RJ, Nyquist P. Falling temperature and colder weather are associated with an increased risk of aneurysmal subarachnoid hemorrhage. World Neurosurg 2013;79:136–42. doi:10.1016/j.wneu.2012.06.020.

[15] Rivera-Lara L, Kowalski RG, Schneider EB, Tamargo RJ, Nyquist P. Elevated relative risk of aneurysmal subarachnoid hemorrhage with colder weather in the mid-Atlantic

region. J Clin Neurosci Off J Neurosurg Soc Australas 2015;22:1582–7. doi:10.1016/j.jocn.2015.03.033.

[16] Chyatte D, Chen TL, Bronstein K, Brass LM. Seasonal fluctuation in the incidence of intracranial aneurysm rupture and its relationship to changing climatic conditions. J Neurosurg 1994;81:525–30. doi:10.3171/jns.1994.81.4.0525.

[17] Lai PMR, Dasenbrock H, Du R. The association between meteorological parameters and aneurysmal subarachnoid hemorrhage: a nationwide analysis. PloS One 2014;9:e112961. doi:10.1371/journal.pone.0112961.

[18] Jehle D, Moscati R, Frye J, Reich N. The incidence of spontaneous subarachnoid hemorrhage with change in barometric pressure. Am J Emerg Med 1994;12:90–1.

[19] Abe T, Ohde S, Ishimatsu S, Ogata H, Hasegawa T, Nakamura T, et al. Effects of meteorological factors on the onset of subarachnoid hemorrhage: a time-series analysis. J Clin Neurosci 2008;15:1005–10. doi:10.1016/j.jocn.2007.07.081.

[20] McDonald RJ, McDonald JS, Bida JP, Kallmes DF, Cloft HJ. Subarachnoid hemorrhage incidence in the United States does not vary with season or temperature. AJNR Am J Neuroradiol 2012;33:1663–8. doi:10.3174/ajnr.A3059.

[21] Jabbour P, Tjoumakaris S, Dumont A, Gonzalez LF, Rosenwasser R. Aneurysm rupture: lunar cycle, weather, atmospheric pressure, myth or reality? World Neurosurg 2011;76:7–8. doi:10.1016/j.wneu.2011.05.041.

[22] Cowperthwaite MC, Burnett MG. The association between weather and spontaneous subarachnoid hemorrhage: an analysis of 155 US hospitals. Neurosurgery 2011;68:132–8; discussion 138-139. doi:10.1227/NEU.0b013e3181fe23a1.

[23] Ali Y, Rahme R, Matar N, Ibrahim I, Menassa-Moussa L, Maarrawi J, et al. Impact of the lunar cycle on the incidence of intracranial aneurysm rupture: myth or reality? Clin Neurol Neurosurg 2008;110:462–5. doi:10.1016/j.clineuro.2008.02.001.

[24] Lahner D, Marhold F, Gruber A, Schramm W. Impact of the lunar cycle on the incidence of aneurysmal subarachnoid haemorrhage: myth or reality? Clin Neurol Neurosurg 2009;111:352–3. doi:10.1016/j.clineuro.2008.11.009.

[25] Peel MC, Finlayson BL, Mcmahon TA. Updated world map of the Köppen-Geiger climate classification. Hydrol Earth Syst Sci 2007:13.

[26] Le Gall JR, Lemeshow S, Saulnier F. A new Simplified Acute Physiology Score (SAPS II) based on a European/North American multicenter study. JAMA 1993;270:2957–63.

[27] Kellogg M, Petrov D, Agarwal N, Patel NV, Hansberry DR, Agarwal P, et al. Effects of Meteorological Variables on the Incidence of Rupture of Intracranial Aneurysms in Central New Jersey. J Neurol Surg Part Cent Eur Neurosurg 2017;78:238–44. doi:10.1055/s-0036-1594308.

[28] Backes D, Rinkel GJE, Algra A, Vaartjes I, Donker GA, Vergouwen MDI. Increased incidence of subarachnoid hemorrhage during cold temperatures and influenza epidemics. J Neurosurg 2016;125:737–45. doi:10.3171/2015.8.JNS151473.

[29] Folsom AR. Fibrinogen and cardiovascular risk markers. Blood Coagul Fibrinolysis Int J Haemost Thromb 1999;10 Suppl 1:S13-16.

[30] Zhang X, Zhang S, Wang C, Wang B, Guo P. Effects of moderate strength cold air exposure on blood pressure and biochemical indicators among cardiovascular and cerebrovascular patients. Int J Environ Res Public Health 2014;11:2472–87. doi:10.3390/ijerph110302472.

[31] Macko RF, Ameriso SF, Gruber A, Griffin JH, Fernandez JA, Barndt R, et al. Impairments of the protein C system and fibrinolysis in infection-associated stroke. Stroke 1996;27:2005–11. doi:10.1161/01.str.27.11.2005.

[32] Sheth T, Nair C, Muller J, Yusuf S. Increased winter mortality from acute myocardial infarction and stroke: the effect of age. J Am Coll Cardiol 1999;33:1916–9. doi:10.1016/s0735-1097(99)00137-0.
[33] Hong Y-C, Rha J-H, Lee J-T, Ha E-H, Kwon H-J, Kim H. Ischemic stroke associated with decrease in temperature. Epidemiol Camb Mass 2003;14:473–8. doi:10.1097/01.ede.0000078420.82023.e3.
[34] Knekt P, Reunanen A, Aho K, Heliövaara M, Rissanen A, Aromaa A, et al. Risk factors for subarachnoid hemorrhage in a longitudinal population study. J Clin Epidemiol 1991;44:933–9.
[35] Lejeune JP, Vinchon M, Amouyel P, Escartin T, Escartin D, Christiaens JL. Association of occurrence of aneurysmal bleeding with meteorologic variations in the north of France. Stroke 1994;25:338–41. doi:10.1161/01.str.25.2.338.
[36] Patrice T, Rozec B, Desal H, Blanloeil Y. Oceanic Meteorological Conditions Influence Incidence of Aneurysmal Subarachnoid Hemorrhage. J Stroke Cerebrovasc Dis O 2017;26:1573–81. doi:10.1016/j.jstrokecerebrovasdis.2017.02.031.
[37] Hughes MA, Grover PJ, Butler CR, Elwell VA, Mendoza ND. A 5-year retrospective study assessing the association between seasonal and meteorological change and incidence of aneurysmal subarachnoid haemorrhage. Br J Neurosurg 2010;24:396–400. doi:10.3109/02688697.2010.499154.
[38] Munarriz PM, Gómez PA, Paredes I, Castaño-Leon AM, Cepeda S, Lagares A. Basic Principles of Hemodynamics and Cerebral Aneurysms. World Neurosurg 2016;88:311–9. doi:10.1016/j.wneu.2016.01.031.
[39] Xia N, Liu Y, Zhong M, Zhuge Q, Fan L, Chen W, et al. Smoking Associated with Increased Aneurysm Size in Patients with Anterior Communicating Artery Aneurysms. World Neurosurg 2016;87:155–61. doi:10.1016/j.wneu.2015.11.094.
[40] Brown RD, Broderick JP. Unruptured intracranial aneurysms: epidemiology, natural history, management options, and familial screening. Lancet Neurol 2014;13:393–404. doi:10.1016/S1474-4422(14)70015-8.
[41] Korja M, Kaprio J. Controversies in epidemiology of intracranial aneurysms and SAH. Nat Rev Neurol 2016;12:50–5. doi:10.1038/nrneurol.2015.228.
[42] Epidemiology of aneurysmal subarachnoid hemorrhage in Australia and New Zealand: incidence and case fatality from the Australasian Cooperative Research on Subarachnoid Hemorrhage Study (ACROSS). Stroke 2000;31:1843–50. doi:10.1161/01.str.31.8.1843.
[43] Nieuwkamp DJ, Setz LE, Algra A, Linn FHH, de Rooij NK, Rinkel GJE. Changes in case fatality of aneurysmal subarachnoid haemorrhage over time, according to age, sex, and region: a meta-analysis. Lancet Neurol 2009;8:635–42. doi:10.1016/S1474-4422(09)70126-7.
[44] Mukhtar TK, Molyneux AJ, Hall N, Yeates DRG, Goldacre R, Sneade M, et al. The falling rates of hospital admission, case fatality, and population-based mortality for subarachnoid hemorrhage in England, 1999-2010. J Neurosurg 2016;125:698–704. doi:10.3171/2015.5.JNS142115.

List of abbreviations

SAH: subarachnoid hemorrhage

SAPS II: Simplified acute physiology score II

WFNS: World Federation of Neurosurgical Societies

SD: Standard deviation

ICU: Intensive care unit

Max: Maximum

Min: Minimum

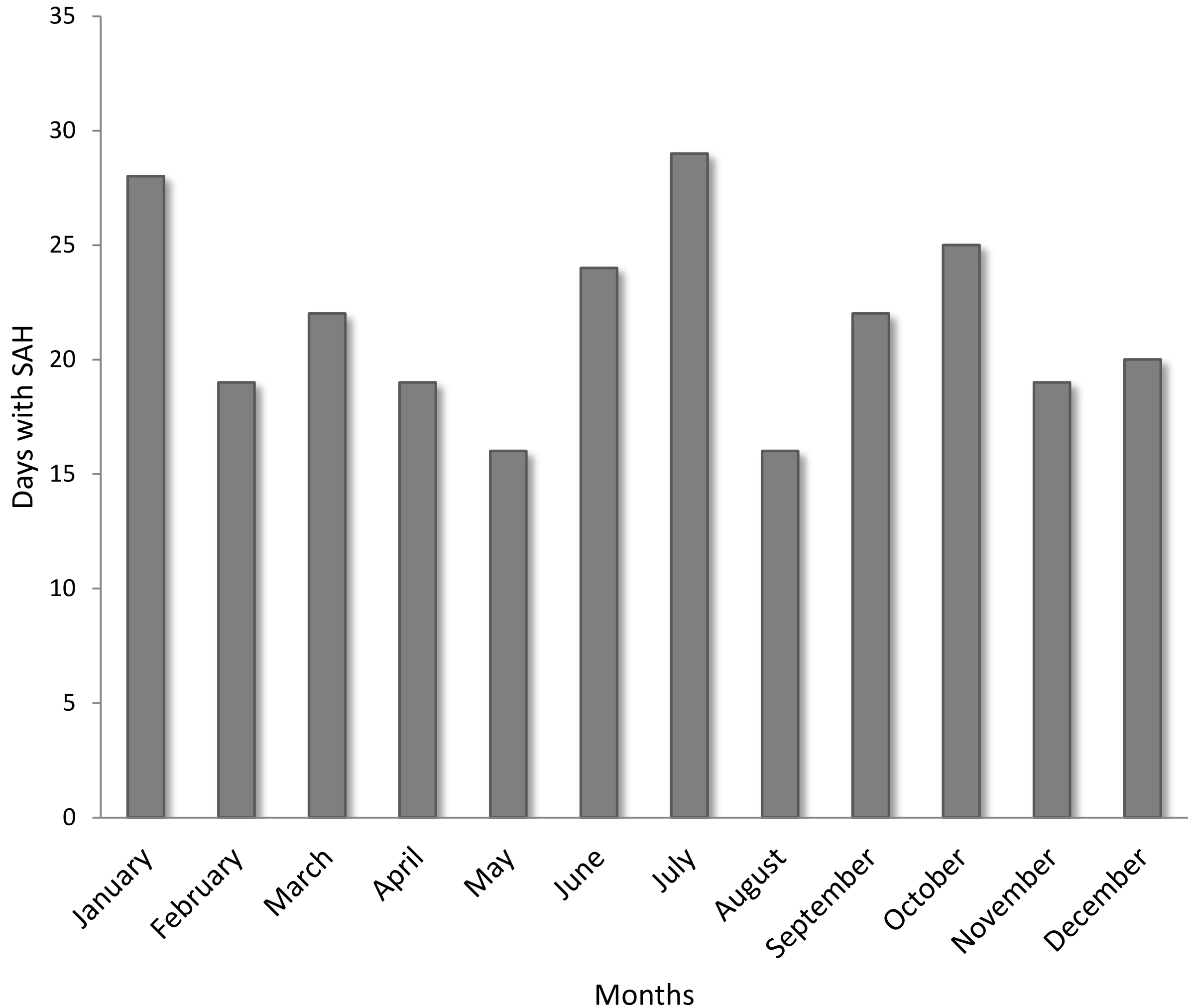
OR: Odds ratio

Figure legends

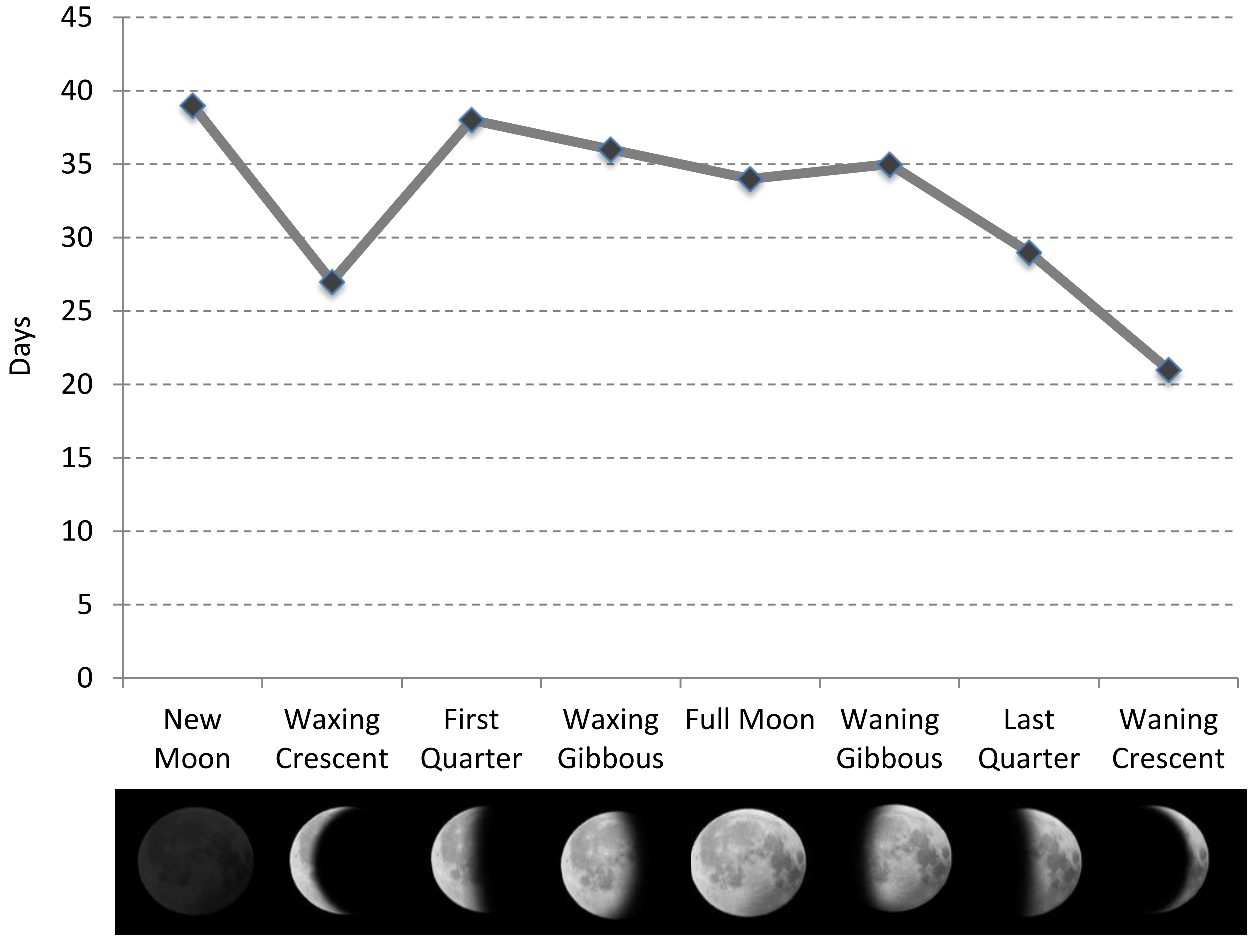
Figure 1: Comparison of incidence of subarachnoid hemorrhage on to a monthly scale (p = 0.26) between January 1st, 2011 and December 31st, 2012.

Figure 2: Effects of Moon phases (p = 0.11) on subarachnoid hemorrhage occurrence. SAH: subarachnoid hemorrhage.

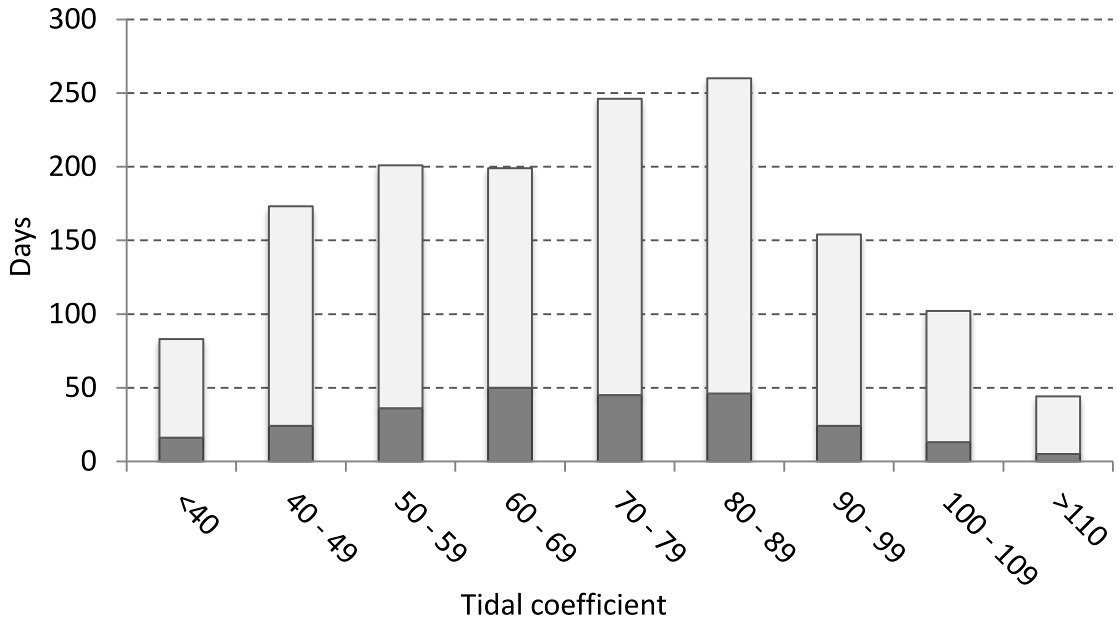
Figure 3: Effects of tidal coefficients (p = 0.12) on subarachnoid hemorrhage occurrence. SAH: subarachnoid hemorrhage. Gray-filled bars: days with SAH; white bars: days without SAH



35
30
25
20
15
10
5
0
Days with SAH
January
February
March
April
May
June
July
August
September
October
November
December
Months



45
40
35
30
25
20
15
10
5
0
Days
New Moon
Waxing Crescent
First Quarter
Waxing Gibbous
Full Moon
Waning Gibbous
Last Quarter
Waning Crescent


300
250
200
150
100
50
0
Days
<40
40 - 49
50 - 59
60 - 69
70 - 79
80 - 89
90 - 99
100 - 109
>110
Tidal coefficient

Characteristics	n = 295
Age (years)	53 ± 13
Sex ratio (Female/Male)	1.76 (188/107)
Hospital center	
Rennes	226 (77%)
Brest	69 (23%)
Cerebral aneurysm risks factors	
Hypertension	74 (25%)
Diabetes	6 (2%)
Familial SAH history	12 (4%)
Polycystic kidney disease	2 (1%)
Smoking	137 (46%)
Alcoholism	20 (7%)
SAPS II score	26 ± 15
Glasgow Coma Scale	13 ± 4
WFNS scale	2 ± 1
Fisher score	3 ± 1
Complications	
Intracranial Hypertension	33 (11%)
Hematoma	38 (13%)
Hydrocephalus	89 (30%)
Vasospasm	71 (24%)
Rebleeding	1 (0.3%)
Ischemia	15 (5%)
Infection	31 (11%)
Overall ICU Mortality	24 (8%)
Overall Hospital Mortality	24 (8%)
ICU stay (days)	7.7 ±8.2
Hospital stay (days)	22.7 ±24.9

Table 1: Patient characteristics. Data are expressed as n(%) or mean ±SD. ICU: Intensive Care Unit; SAPS II: Simplified Acute Physiology Score; SAH: Subarachnoid hemorrhage; WFNS: World Federation of Neurosurgical Societies

WFNS scale	SAH n = 295	Mortality n = 24‡
grade 1	163 (55%)	5 (3%)
grade 2	57 (19%)	4 (7%)
grade 3	23 (8%)	1 (4%)
grade 4	24 (8%)	6 (25%)
grade 5	28 (10%)	8 (28%)
Fisher classification		
grade 1	66 (22%)	2 (3.2%)
grade 2	47 (16%)	2 (4.5%)
grade 3	48 (16%)	2 (4.2%)
grade 4	134 (46%)	18 (13.5%)

Table 2: Subarachnoid hemorrhage (SAH) severity classification according to the World Federation of Neurosurgeons Society (WFNS) or Fisher scale, and corresponding in-hospital mortality according to grade. Data are expressed as *n* (%).
‡ 2 missing patients for alive status.

Aneurysm characteristics	n = 295
Aneurysm location	
Anterior cerebral artery	100 (34%)
Middle cerebral artery	65 (22%)
Posterior cerebral artery	17 (6%)
Internal carotid artery	50 (17%)
Vertebro-basilar artery	25 (8%)
Sine materia	38 (13%)
Aneurysm size (mm)	5.8 ±3.2
Aneurysm treatment	
Coiling	226 (77%)
Surgical	23 (7%)
None	46 (16%)

Table 3: Aneurysm characteristics and type of treatment. Data are expressed as *n(%)* or mean± SD.

Climate variables	Days with SAH (n=259)	Days without SAH (n= 1203)	p-value
Temperature (°Celsius)			
Maximum	16 ±5.8	16.3 ±16.3	0.41
Minimum	7.7 ±4.7	8.3 ±4.7	<0.05*
Barometric pressure (hPa)			
Maximum	1,021.3 ±8.5	1,020.4 ±8.8	0.12
Minimum	1,015.8 ±9.8	1,014.7 ±10.1	0.10
Relative humidity (%)			
Maximum	95.4 ±4.4	95.8 ±4.0	0.26
Minimum	63.2 ±16.7	63.5 ±15.5	0.72
Wind speed (km.h^{-1})			
Average	13.8 ±6.4	14.5 ±6.6	0.14
Maximum	41.2 ±15.4	40.0 ±14.4	0.22

Table 4: Effects of meteorological parameters on subarachnoid hemorrhage (SAH) occurrence. Data are expressed as mean ± SD.

Variations	Days with SAH (n=259)	Days without SAH (n= 1203)	p value
Temperature (°Celsius)			
D0max - D0min	8.3 ±4.3	8 ±4.0	0.20
D-1max - D0min	8.6 ±4.1	7.9 ±3.8	<0.05*
D0max - D-1min	8.1 ±4.7	8 ±4.3	0.84
Barometric pressure (hPa)			
D0max - D0min	5.5 ±3.6	5.7 ±3.8	0.31
D-1max - D0min	5.7 ±5.8	5.7 ±5.7	0.99
D0max - D-1min	5.5 ±5.8	5.7 ±6.2	0.75
Relative humidity (%)			
D0max - D0min	32.3 ±15.8	32.2 ±14.7	0.95
D-1max - D0min	32.3 ±16.5	32.3 ±15.5	0.99
D0max - D-1min	32.8 ±15.9	32.1 ±15.7	0.52

Table 5: Effects of meteorological variations on subarachnoid hemorrhage occurrence. D0max – D0min: variations of the climatic variable within a day; D-1max – D0min: drop in climatic variable between one day (D0) and the day before (D-1); D0max – D-1min: rise in climatic variable between one day (D0) and the day before (D-1). max: maximum; min: minimum; SAH: subarachnoid hemorrhage. Data are expressed as mean ±SD**.**

Climate variables	WFNS 1 (n=163)	WFNS 2 (n=57)	WFNS 3 (n=23)	WFNS 4 (n=24)	WFNS 5 (n=28)	p-value
Temperature (°Celsius)						
Maximum	15.7±5.8	15.8±5.6	15.1±6.4	15.4±4.8	13.5±5.7	0.74
Minimum	7.8±4.6	8.1±5.0	6.7±5.1	7.0±3.2	6.5±5.7	0.76
Variation	7.9±4.1	7.6±3.9	8.4±4.2	8.4±3.9	7.0±3.1	0.70
Barometric pressure (hPa)						
Maximum	1,016.4±10.9	1,015.9±9.6	1,014.0±8.8	1,015.0±9.7	1,014.4±9.8	0.43
Minimum	1,022.1±8.9	1,021.1±8.4	1,020.7±8.1	1,020.9±9.1	1,019.9±9.3	0.43
Variation	5.7±4.1	5.2±3.3	6.7±4.1	5.9±3.6	5.6±4.1	0.67
Relative humidity (%)						
Maximum	94.7±4.3	95.7±2.9	93.9±4.5	94.2±6.0	94.3±4.0	0.34
Minimum	63.0±16.1	65.7±16.2	62.3±15.1	60.4±16.7	64.5±13.4	0.67
Variation	31.7±15.2	30.0±15.8	31.6±14.6	33.8±14.6	29.7±13.3	0.83
Wind speed ($km.h^{-1}$)						
Average	13.9±6.1	12.5±6.0	11.6±5.3	14.3±6.3	14.9±8.8	0.21
Maximum	40.1±15.0	36.0±14.1	34.1±11.2	40.4±15.2	44.1±20.3	0.07

Table 6: Effects of climatic variables and their variation on subarachnoid hemorrhage (SAH) severity score assessed by World Federation of Neurosurgical Societies (WFNS) score. Data are expressed as mean ± SD.