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Intracranial Aneurysm Rupture Is Predicted by Measures of Solar Activity

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Key words
- Aneurysmal subarachnoid hemorrhage
- Geomagnetic energy
- Intracranial aneurysm
- Rupture risk
- Solar activity
- Temporal clustering

Abbreviations and Acronyms

Ap: Planetary A-index
aSAH: Aneurysmal subarachnoid hemorrhage
BP: Blood pressure
95% CI: 95% confidence interval
CME: Coronal mass ejection
DBP: Diastolic blood pressure
GMA: Geomagnetic activity
GOES: Geostationary Operational Environmental Satellite
IRB: Institutional research board
IRR: Incidence rate ratio
Kp: Planetary K-index
NOAA: National Oceanic and Atmospheric Administration
RF: Rupture frequency
SBP: Systolic blood pressure
SE: Standard error
SESC: Space Environment Services Center

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■ OBJECTIVE: **The cause precipitating intracranial aneurysm rupture remains unknown in many cases. It has been observed that aneurysm ruptures are clustered in time, but the trigger mechanism remains obscure. Because solar activity has been associated with cardiovascular mortality and morbidity, we decided to study its association to aneurysm rupture in the Swiss population.**

■ METHODS: **Patient data were extracted from the Swiss SOS database, at time of analysis covering 918 consecutive patients with angiography-proven aneurysmal subarachnoid hemorrhage treated at 7 Swiss neurovascular centers between January 1, 2009, and December 31, 2011. The daily rupture frequency (RF) was correlated to the absolute amount and the change in various parameters of interest representing continuous measurements of solar activity (radioflux [F10.7 index], solar proton flux, solar flare occurrence, planetary K-index/planetary A-index, Space Environment Services Center [SESC] sunspot number and sunspot area) using Poisson regression analysis.**

■ RESULTS: **During the period of interest, there were 517 days without recorded aneurysm rupture. There were 398, 139, 27, 12, 1, and 1 days with 1, 2, 3, 4, 5, and 6 ruptures per day. Poisson regression analysis demonstrated a significant correlation of F10.7 index and RF (incidence rate ratio [IRR] = 1.006303; standard error (SE) 0.0013201; 95% confidence interval (CI) 1.003719−1.008894; $P < 0.001$), according to which every 1-unit increase of the F10.7 index increased the count for an aneurysm to rupture by 0.63%. A likewise statistically significant relationship of both the SESC sunspot number (IRR 1.003413; SE 0.0007913; 95% CI 1.001864−1.004965; $P < 0.001$) and the sunspot area (IRR 1.000419; SE 0.0000866; 95% CI 1.000249−1.000589; $P < 0.001$) emerged. All other variables analyzed showed no significant correlation with RF.**

■ CONCLUSIONS: **We found greater radioflux, SESC sunspot number, and sunspot area to be associated with an increased count of aneurysm rupture. The clinical meaningfulness of this statistical association must be interpreted carefully and future studies are warranted to rule out a type-1 error.**

INTRODUCTION

Various intrinsic risk factors for aneurysmal subarachnoid hemorrhage (aSAH) have been identified, including aneurysm-related factors such as location, size, and configuration (38), of which aneurysm location and size are the factors being regarded most relevant (6, 28, 33, 53). Although many of these surrogates frequently are used to estimate rupture risk, their predictive value is low. Small aneurysms may rupture, and some large aneurysms remain stable during a long period of follow-up. Today, our understanding of the mechanisms underlying aneurysm rupture remains to be insufficient. Advanced imaging studies have begun to help elucidate the relationship between the anatomy, morphology, and hemodynamic patterns. Recently, reconstructions from 3-dimensional angiography images allowed us to identify surface and hemodynamic features like concentrated inflow jets, small impingement regions, complex flow patterns, and unstable flow patterns to be correlated with a clinical history of prior aneurysm rupture (9).

In contrast, stable patterns, large impingement regions, and jet sizes were more commonly observed in unruptured aneurysms (8). Intracranial aneurysms must thus not be regarded as static but dynamic structures, and morphologic characteristics are subject to change over time. Beyond morphologic aneurysm-related characteristics that help to determine the rupture risk, further patient-related intrinsic risk factors have been identified. These include hypertension (18), nicotine consumption (18), excessive alcohol intake, and physical activity, among others (11, 21, 69). Likewise, genetic factors relate to a greater intrinsic risk of aneurysm rupture (1, 71, 72).

In addition, extrinsic risk factors seem to exist, as a temporal clustering of SAH admissions repeatedly has been recognized with a wave-like pattern of aSAH patient admissions (23, 29, 31, 39, 40, 47, 49, 70). It is likewise our group's experience that after several days without aSAH patient admission, a multitude of patients may be admitted during a 4- or 5-day period, sometimes even several patients per day. Clustering with associated strong variations in the admission pattern can lead to capacity problems because of the limited number of intensive care unit beds in the department. Furthermore, it is conceivable, that this factor may even influence the quality of treatment and subsequent outcome.

Therefore, extrinsic factors with possible influence on the variation in aSAH admission should be identified. Most studies on extrinsic risk factors for aneurysm rupture have concentrated on meteorologic factors (5, 27, 39, 40, 47). The majority of studies have suggested that the incidence of aSAH is impacted by the climate and further seasonal and circadian factors (19, 23, 24, 32, 42, 49, 63), whereas other studies could not show any influence (13, 20, 34, 48, 60). Some studies found seasonal influence on aSAH admission only in patients of certain age groups (23, 31, 47) or of certain sex (10, 52). The main mechanism assumed to underlie possible seasonal or meteorologic influence on aneurysm rupture is the patients' change in blood pressure in relation to the environmental temperature (e.g., coldness-induced hypertension) (5, 40, 61, 70). Still, as other studies found SAH peaks in warm spring and summer months (3, 40, 47, 57), aSAH cannot be ascribed to this seasonal mechanism alone. Further studied variables were atmospheric pressure (5, 7, 39, 40, 61), humidity (5, 40, 61), and duration of sunshine (40). A recently published study in which the authors used high-quality data and robust statistical methods suggested no relevant influence of any meteorologic parameter on the incidence of aSAH, which is likely to put an end to the discussion about terrestrial meteorological impact on this disease (48).

Recently, further authors have concentrated on extra-terrestrial extrinsic risk factors in an attempt to solve the riddle of extrinsic influence on aSAH (2, 35, 37). Despite previously reported positive associations (2), it could be shown that the lunar circle has no impact on aneurysm rupture (35, 37). A possible influence of solar activity on aneurysm rupture has not yet been studied despite previous reports in the literature that solar activity may be capable of influencing human physiology and health (12, 14-16, 30, 43, 44, 46, 50, 56, 62, 64-68, 73).

We focused on the pattern of aneurysm rupture in Switzerland and analyzed whether solar activity had any influence on rupture rates of intracranial aneurysms. The null hypothesis was that solar activity is not associated with an increased likelihood of aneurysm rupture.

METHODS

Patient data were derived from the Swiss SOS database, covering 918 patients with angiography-proven aSAH treated at 7 Swiss neurovascular centers between 1 January 2009 to 31 December 2011 at the time of analysis (59). The local institutional review boards (IRBs) of every participating center approved to the study protocol: Kantonsspital Aarau (Kantonale Ethikkommission Aargau), University Hospital Basel (Ethikkommission Basel Stadt/Basel Land), University Hospital Berne (Kantonale Ethikkommission Bern), University Hospital Geneva (Commission centrale d'éthique de la recherche), University Hospital Lausanne (Commission cantonale [VD] d'éthique de la recherche), Kantonsspital St. Gallen (Kantonale Ethikkommission St. Gallen), and University Hospital Zurich (Kantonale Ethikkommission Zürich). The coordinating IRB was the University of Geneva ethics committee (Commission centrale d'éthique de la recherche), where the study was registered under "11-233R (NAC 11-085R)."

Acquisition of patient data was performed by physicians directly involved in the treatment or follow-up of the involved subjects, and further analyses were based on anonymous data. At most centers, written informed consent was not necessary in accordance with institutional guidelines and the federal law (waiver issued by the local IRB). At all centers where this was requested by the local IRB, written informed consent was obtained by each participant (or next of kin/caregiver).

The aneurysm rupture frequency (RF) per each day between 1 January 2009 and 31 December 2011 was extracted and then correlated to relevant parameters of solar activity that were provided by the National Oceanic and Atmospheric Administration (NOAA).

Parameters of Solar Activity

The Sun exhibits a variety of activity signatures. Phenomena such as solar flares, coronal mass ejections (CMEs), and the solar wind can have a direct effect on the Earth's atmosphere and magnetosphere. Solar flares are powerful explosions in the solar atmosphere, accelerating large amounts of charged particles (predominantly electrons and protons) to near light-speed and exhibiting strong X-ray and ultra-violet radiation (**Figure 1**). CMEs (= clouds of plasma and magnetic flux) often are linked to solar flares. CMEs and solar wind shock waves lead to compression of the magnetosphere with an increased amount of energy being transferred into the Earth's magnetosphere, causing geomagnetic disturbance. Energetic particles that become trapped in the inner magnetosphere and strong X-ray as well as ultraviolet irradiance change the upper atmospheric chemistry (see 55 for a review). Solar activity has been constantly monitored for many centuries, initially by counting the numbers of sun spots. Today, a large number of instruments, both on the