Meteorological Factors and Seasonal Stroke Rates: A Four-year Comprehensive Study

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Introduction: There is a growing body of evidence suggesting that acute cardiovascular events including stroke are not distributed randomly over time but instead depend on months/season of the year. We report the impact of meteorological variables in extremely hot and arid climate on stroke. *Methods:* Acute stroke patients admitted from January 2014 to December 2017 were included. The data included demographics, clinical risk factors, temperature, solar radiation, relative humidity, dew point, wind speed, and atmospheric pressure. We calculated stroke rates/100,000/month. *Results:* There were 3654 cases of stroke (ischemic stroke [IS]: 2956 [80.9%]; and intracerebral hemorrhage [ICH]: 698 [19.1%]) with no difference in hematocrit, creatinine, and blood urea between hot and cold seasons ($p > .05$). We observed a positive significant correlation of IS with the mean temperature (AOR: 1.023; 95% CI: 1.009-1.036; $P = .001$) and mean solar radiation (AOR: 1.268; 95% CI: 1.021-1.575; $P = .032$) showing a 2.3% and 26.8% higher risk relative to ICH respectively, a negative correlation between IS with relative humidity (AOR: 0.99; 95% CI: 0.984-0.997; $P = .002$), and atmospheric pressure (AOR: 0.977; 95% CI: 0.966-0.989; $P < .001$) was observed, 1% increase in the relative humidity correlate with 2.4% and 1% lower risk of IS incidence relative to ICH respectively. *Conclusion:* We demonstrated a distinct seasonal pattern in the incidence of stroke with an increase in IS rates relative to ICH during the summer months with higher solar radiations that cannot be explained by physiological measures suggestive of dehydration or hemconcentration.

Key Words: Ischemic stroke—ICH—season—meteorological data

Introduction

The concept of climatic influence upon cardiovascular and stroke events is biologically plausible and epidemiological supported, suggesting that these events are not randomly distributed over time, but instead depend on the season of the year.[1-4] It has been shown that ambient temperature challenges have a direct and highly varied impact on cardiovascular health by activation of the sympathetic nervous system, renin-angiotensin system, as well as dehydration and a systemic inflammatory response.[1]

The deleterious effects of extremes of climatic stress are more noticeable in the elderly[5] and in patients with

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vascular risk factors, especially hypertension (HTN) and diabetes (DM).[6] However, considerable uncertainty remains regarding the nature and validity of the relationship between climatic influence upon cardiovascular health in general and stroke risk in particular. While some studies suggest that risk of stroke either increases[7,8] or remains constant throughout the year[9] others have reported higher rates in summer-autumn.[10-12] With ongoing climate change, particularly warming climate interest in understanding temperature-related health effects is growing.

The Arab peninsula experiences extremely high temperatures and solar radiation during the summer months. The climate is characterized by intense heat throughout summer with very high humidity in combination with high temperatures in the later part of summer. Reports on the effects of extremely hot weather from hot arid regions on the rates of stroke are however very rare.[13] The purpose of the present study was to determine whether seasonal variation in stroke incidence exists and whether this variation is related to meteorological factors in the extremely hot and arid region of Qatar, a state in the Arabian Peninsula. An understanding of the mechanisms, especially with extremes of temperature is important for the development of preventive measures.

Materials and Methods

Area and Population characteristics

The state of Qatar is a small and flat country on the eastern coast of the Arabian Peninsula with a total average population of 2,403,370 that remained stable during 4 years of the study period [2014-2017]. There is a gender imbalance in the population (men, 75%; women, 25%) due to the large expatriate workforce being predominantly male. (Ministry of Development Planning and Statistics. https://www.mdps.gov.qa/en/statistics1/statisticssite/pages/population.aspx?p=2).

Regional Climate

The state of Qatar has a dry, subtropical desert climate with a very mild winter and a very hot and sunny summer. Due to its geography, the climate is uniform throughout the territory. The weather in Qatar is tropical maritime with 2 main seasons: a cold season from November to March, and a hot season from April to October with mid-March to mid-April and mid-October to mid-November being the transitional months [https://qweather.gov.qa/Index.aspx]. The summer is characterized by intense dry heat in early part of summer later replaced by humidity and heat. Within the hot season is the very hot period from May to September with temperatures soaring to above 50°C (122°F). The relative humidity gradually increases over the course of summer months with the highest humidity in August and September. The combination of moisture and temperature, observed in summer in the countries of the Arabian Gulf, is actually one of the worst in the world. The rainfall in Qatar is scarce (<100 millimeters [4 inches] per year), occurring during the winter months while in summer it almost never rains. In the summer, the moist wind blows from the northwest frequently. Yet a hot and dry wind can blow throughout the year, but usually in spring from the south. These winds are capable of raising the temperatures to above 30°C (86°F) in winter and above 50°C (104°F) from April to October. They also lead to dust and sandstorms and drastically lower the relative humidity.

Patients

All acute stroke patients admitted to the hospital from January 2014 to December 2017, were included in the study. Stroke was diagnosed using the Trial of Org 10172 in Acute Stroke Treatment classifications.[14] The medical data were collected in a prospective stroke-database at a Joint Commission International accredited, tertiary referral center, and teaching affiliate of a medical school, treating 98% of all acute stroke patients. While the meteorological data were prospectively collected on a daily basis by the meteorology department and civil aviation authority of the state of Qatar. The data included demographics, clinical risk factors, temperature, solar radiation, relative humidity, dew point temperature, wind speed, and atmospheric pressure.

Statistical Methods

Descriptive and inferential statistics were used to characterize the study sample and test hypotheses. Descriptive results (including graphical displays) for all quantitative variables (e.g., age) are presented as the mean ± standard deviation (SD) (for normally distributed data) or median with interquartile range (for data not normally distributed). Numbers (percentage) were reported for all qualitative variables (e.g., gender). Bivariate analysis was performed using Independent sample *t* test, and the Mann Whitney *U* test to compare the average for all quantitative variables (e.g., age) between stroke subtypes (Ischemic stroke [IS] versus intracerebral hemorrhage [ICH]), whenever appropriate, while the Pearson chi-square test or Fisher Exact test as appropriate were used to compare all the qualitative variables (e.g. gender) between stroke subtypes (IS versus ICH). The stroke attack rate was defined as the average number of strokes occurring in the study period per 100,000 people per month.

A binary variable for the seasons in Qatar was created with 2 levels (1 = hot season, 0 = cold season). The Pearson chi-square test was used to compare the stroke incidence (IS versus ICH) between 2 main seasons (hot and cold season). Bivariate analysis was performed using Independent sample *t* test, and the Mann Whitney *U* test to compare the average for all quantitative variables (e.g., age) between 2 seasons (hot and cold season), whenever appropriate, while the Pearson chi-square test or Fisher Exact test as appropriate were used to compare all the qualitative variables (e.g. gender) between 2 seasons (hot and cold season). Pearson correlation test was used to assess the association between meteorological variables (temperature, relative humidity, dewpoint temperature, wind speed, rainfall, atmospheric pressure, and solar radiation) with average stroke rate per 100,000 people per month. Multiple Binary logistic regression models were used to assess the relationship between 2 main seasons (Hot versus cold) and stroke subtypes after adjusting for potentially confounding factors such as age, gender, hypertension, diabetes, dyslipidemia, atrial fibrillation (AF) on admission, and smoking). Similar analysis was used to assess the impact of one unit increase in monthly average temperature, relative humidity, dewpoint temperature, wind speed, atmospheric pressure, and solar radiation on the stroke subtypes after adjusting for potentially confounding factors such as age, gender, HTN, DM, Dyslipidemia, AF on admission, and smoking). We ran 2 separate multiple logistic regression models depending on the dependent variables as IS (coding 1) versus ICH (coding 0) and ICH (coding 1) versus IS (coding 0). The Wald test was computed on each predictor to determine which were significant. Adjusted odds ratio and 95% confidence interval for the adjusted odds ratio were reported. A "P" value <.05 (2-tailed) was considered statistically significant. The Hosmer-Lemeshow Goodness-of-fit statistics were used to determine whether the model adequately describes the data. All statistical analyses were performed using Statistical Package for Social Sciences Version 22 (SPSS).

Results

During 4 years of study period between January 1, 2014 and December 31, 2017, the total average population of Qatar was 2,403,370 and 3654 cases of stroke (IS: 2956 [80.9%]; and ICH: 698 [19.1%]) were recorded in the stroke database. The mean age of patients was 54.4 ± 13.2 years with 82·0% males. The incidence rates, demographics, risk factors of stroke, and meteorological data according to the season (hot and cold) are shown in Table 1. There was significant ($P < .001$) increase in all strokes (AS) and particularly IS in the hot season compared to the cold season, while the ICH rate was lowest in the hot season compared to cold (Table 1). There was no significant difference in age, gender, and risk factors according to seasons. The mean values of the meteorological variables showed a significant difference between hot and cold season (Table 1).

Table 1. *Distribution of demographic, risk factors, toast classification, and meteorological variables according to season, Doha, Qatar, 2014-2017*

Characteristics	Total Qatar population N (%)	All stroke n = 3654	Cold season n = 1767	Hot season n = 1887	P value*
Overall	2,403,370€				
Female	582,490 (25.0)				
Male	1,820,879 (75.0)				
Sex (Male) $^{(n = 3654)}$		3017 (82.6)	1440 (18.5)	1577 (83.6)	.098
Age		54.43 ± 13.21	54.56 ± 13.38	54.32 ± 13.04	.581†
Presence of risk factors history					
• HTN		2709 (74.1)	1315 (74.4)	1394 (73.9)	.706
• DM		1885 (51.6)	890 (50.4)	995 (52.7)	.153
• Dyslipidemic		1783 (48.8)	848 (48.0)	935 (49.5)	.346
• AF on ADM		259 (7.1)	126 (7.1)	133 (7.0)	.923
• Smoking		860 (23.5)	393 (22.2)	467 (24.7)	.074
Final Diagnosisβ					<.001
• IS		2956 (80.9)	1380 (37.8)	1576 (43.1)	
• ICH		698 (19.1)	387 (10.6)	311 (8.5)	
Meteorological data					
• Temperature (°C)		29.41 ± 6.66	23.46 ± 4.02	34.98 ± 2.56	<.001†
• Wind speed (m/s)		3.50 ± 0.52	3.48 ± 0.40	3.52 ± 0.62	.047†
• Humidity (%)		52.45 ± 14.40	61.11 ± 11.65	44.34 ± 11.78	<.001†
• Dew point temperature (°C)		16.74 ± 5.30	14.56 ± 3.44	18.77 ± 5.90	<.001†
• Atmospheric Pressure (hPa)		1009.70 ± 7.59	1016.38 ± 3.17	1003.43 ± 4.57	<.001†
• Solar Radiation (joules/cm^3)		2095.02 ± 487.83	1654.14 ± 306.84	2439.12 ± 282.96	<.001†

Abbreviations: IS: Ischemic stroke, ICH: Intracerebral hemorrhage.
Results are expressed as mean ± standard deviation, number (percentage).
*P value has been calculated using Pearson chi-square test.
†P value has been calculated using Independent sample t test. β Percentage for the final diagnosis has been calculated using: Number of observation/total number of cases. For example, IS in cold season = 1380/3654 (37.8%).

The crude monthly AS rates and data on mean meteorological variables (temperatures, wind speed, relative humidity, dew point temperature, rainfall, atmospheric pressure, and solar radiation) are shown in Table 2 and Figure 1. The monthly AS incidence rate was the highest in August 14.8/100,000 (per 100,000 population), and the lowest in December 10.8/100,000 population. A high incidence rate was observed for IS 13.0/100,000 people in August while the incidence rate of ICH that was the lowest in August 1.8/100,000 people. The mean monthly temperatures increased from 19.0°C in December to 37.6°C in July with a corresponding increase in the solar radiation index (from 1491 to 2586) and a decrease in humidity (from 64.3% to 43.8%). The association of changes in each meteorological variable with changes in the average stroke rate per 100,000 population per month was separately calculated [Table 2]. There was significant positive correlation of average monthly temperature (Pearson correlation coefficient [r] = 0.622, P = .031), and average solar radiation (r = 0.68, P = .014) with average stroke rate per 100,000 per month, while average atmospheric pressure showed a significant negative correlation (r = −0.77, P = .003). We did not find any statistically significant association between average wind speed, relative humidity, and dew point temperature with the average stroke rate.

Multiple Logistic Regression Model

Seasonal Impact on Stroke Rate

In a multiple binary logistic regression model showing the risk of stroke in hot season was 1.39 (AOR: 1.39; 95% CI: 1.167-1.661; $P < .001$) times more compared to cold season after adjusting for demographic variables (age, gender, nationality), and risk factor of stroke (HTN, DM, dyslipidemia, AF on admission, and smoking) [Table 3].

Meteorological Variables Impact on Stroke Rate

For each 1-unit increase in the mean temperature (°C), relative humidity (%), atmospheric pressure (hPa), and solar radiation (joules/cm2) on the stroke subtype (IS over ICH), after adjusting for confounding variables is shown in Tables 4-5. While there was a positive statistically significant correlation of IS with the mean temperature (AOR: 1.023; 95% CI: 1.009-1.036; P = .001; Table 4) and mean solar radiation (AOR: 1.268; 95% CI: 1.021-1.575; P = .032; Table 5) showing a 2.3% and 26.8% higher risk of IS incidence relative to ICH respectively, a statistically negative correlation between IS with relative humidity (AOR: 0.99; 95% CI: 0.984-0.997; P = .002; Table 4) and atmospheric pressure (AOR: 0.977; 95% CI: 0.966-0.989; $P < .001$; Table 5) with incidence of stroke was observed (1% increase in the relative humidity correlate with 2.4% and 1% lower risk of IS incidence relative to ICH respectively) (Tables 4-5).

Table 2. *Monthly stroke attack rate and average monthly temperature, wind speed, relative humidity, dew point temperature, atmospheric pressure, solar radiation characteristics of Doha Qatar, From January 1, 2014 to December 31, 2017*

Month	Stroke attack rate per 100,000 people per month			Temperature °C	Wind speed (m/s)	Relative humidity (%)	Dew point temperature (°C)	Atmospheric pressure (hPa)	Solar radiation (joules/cm2)	Average total population per month
	All stroke	IS	ICH							
January	264 (11.4)	202 (8.7)	62 (2.7)	19.2	3.2	67.9	12.6	1019.6	1483.8	2310128.8
February	316 (13.1)	250 (10.3)	66 (2.7)	19.5	3.8	64.9	12.1	1018.0	1587.1	2417263.5
March	315 (13.0)	251 (10.4)	64 (2.6)	23.5	3.8	61.3	14.6	1014.3	1836.3	2419272.0
April	310 (12.7)	253 (10.4)	57 (2.3)	28.9	3.7	41.2	12.6	1011.3	2393.9	2433240.0
May	289 (11.8)	233 (9.5)	56 (2.3)	34.2	3.7	35.5	14.2	1006.4	2584.5	2459249.5
June	330 (13.9)	272 (11.4)	58 (2.4)	36.4	4.4	32.0	13.7	1000.7	2743.9	2379808.8
July	309 (13.9)	263 (11.9)	46 (2.1)	37.7	3.6	43.2	20.5	997.8	2588.5	2209618.8
August	342 (14.8)	301 (13.0)	41 (1.8)	36.6	3.1	55.7	25.3	1000.0	2431.9	2308427.7
September	302 (12.3)	243 (9.9)	59 (2.4)	34.8	3.0	52.9	22.8	1005.1	2137.3	2458317.7
October	321 (12.9)	258 (10.3)	63 (2.5)	31.5	3.1	52.8	19.4	1011.3	1794.3	2498812.3
November	295 (11.7)	226 (8.9)	69 (2.7)	25.9	3.4	58.2	16.6	1016.4	1500.4	2529856.7
December	261 (10.8)	204 (8.4)	57 (2.4)	21.5	3.3	68.2	14.6	1019.8	1324.1	2416442.0

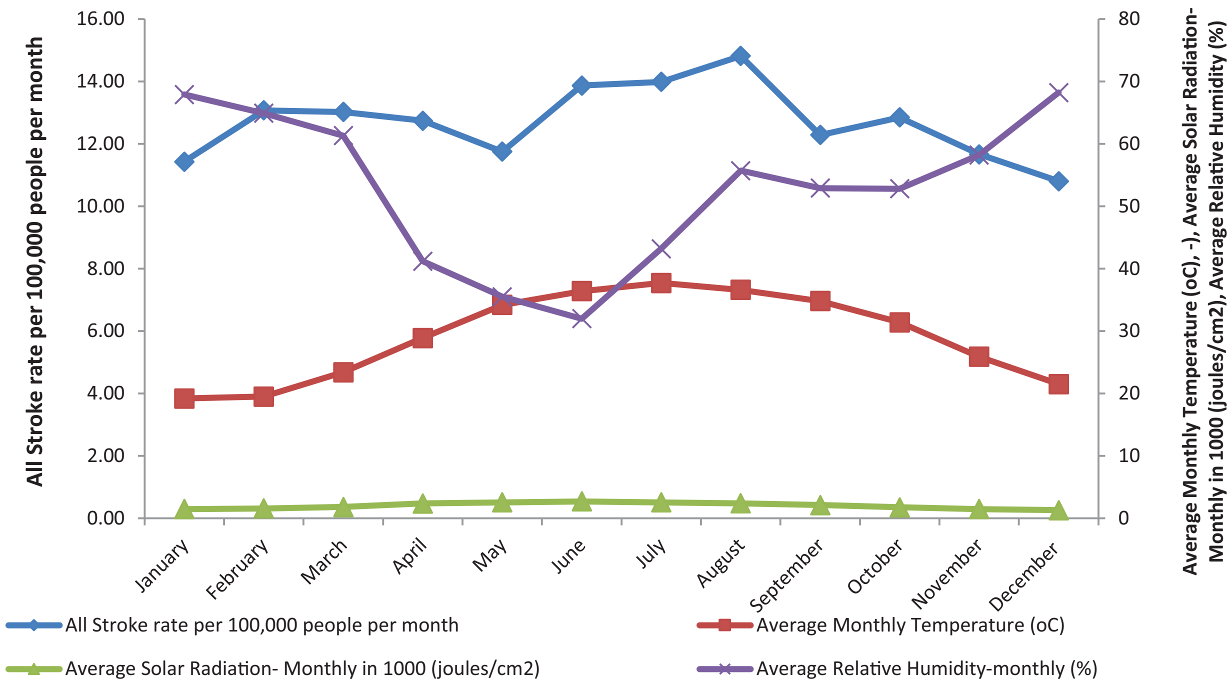

Figure 1. *Relationship between stroke attack rate per 100,000 people per month and meteorological variables (solar radiation in 1000 (joules/cm^2), temperature (°C) and relative humidity (%) in Qatar during 2014 through 2017. (Color version of figure is available online.)*

Discussion

Our data shows that stroke exhibits seasonal characteristics, with increased rates of stroke in the summer and decreased rates in the winter. Compared to winter months, there was a 6.8% increase in the number of total stroke admissions during the summer months. The increase was primarily driven by an increase in ISs. A milder but statistically significant higher rate of ICH in the winter months was observed. There was a positive correlation of IS with the mean temperature and mean solar radiation showing a 2.3% and 26.8% higher risk of IS incidence relative to ICH respectively. On the other hand, we observed a positive correlation between ICH with relative humidity and atmospheric pressure showing a 2.4% increase in ICH. These changes were independent of any change in the traditional risk factors for stroke. We found no seasonal variation in the history of conventional risk factors, which is in line with a recent study, indicating that the meteorological variables may, at least in part, play as risk factors for stroke independent of other risk factors.[15]

Table 3. *Multiple Binary Logistic Regression Model to examine the impact of season on stroke subtype (IS vs ICH) after adjusting for demographics and potential risk factors*

Factor	Adjusted odds ratio (AOR)*	95% CI for AOR	*P* value†
Season			
• Cold Season	1		
• Hot Season	1.392	(1.167-1.661)	<.001
Age (In years)	1.020	(1.012-1.028)	<.001
Gender(Male)	0.792	(0.619-1.015)	.065
Presence of risk factors history			
• HTN	0.407	(0.324-0.511)	<.001
• DM	2.438	(2.013-2.952)	<.001
• Dyslipidemia	2.282	(1.898-2.742)	<.001
• AF on ADM	3.506	(2.062-5.960)	<.001
• Smoking	3.618	(2.752-4.758)	<.0001

Abbreviations: AOR: Adjusted odds ratio; CI: Confidence Interval.
Hosmer and Lemshow goodness of fit test (chi-square value = 13.58, df = 8 and *P* value = .093).
Results are expressed as AOR and 95% confidence interval for AOR. Reference category is indicated by OR = 1.
*AOR of IS over ICH.
†*P* value has been calculated using Wald test statistics.

Table 4. *Adjusted odds ratio and 95% confidence intervals using multiple binary logistic regression model to examine the impact of 1 unit increase in the mean temperature and relative humidity on stroke subtype (IS over ICH) after adjusting for demographics and potential risk factors*

Factor	Mean temperature (°C) AOR* (95% CI)	*P* value†	Relative humidity AOR* (95% CI)	*P* value†
IS	1.023 (1.010-1.036)	.001	0.991 (0.984-0.997)	.003
Age (In years)	1.020 (1.013-1.028)	<.001	1.020 (1.013-1.028)	<.001
Gender (Male)	0.794 (0.620-1.017)	.068	0.794 (0.620-1.017)	.068
Presence of risk factors history				
• HTN	0.408 (0.325-0.512)	<.001	0.401 (0.319-0.503)	<.001
• DM	2.428 (2.006-2.940)	<.001	2.460 (2.032-2.977)	<.001
• Dyslipidemia	2.284 (1.900-2.744)	<.001	2.302 (1.916-2.767)	<.001
• AF on ADM	3.515 (2.068-5.974)	<.001	3.456 (2.034-5.870)	<.001
• Smoking	3.594 (2.733-4.725)	<.001	3.581 (2.724-4.709)	<.001

Abbreviations: AOR: Adjusted odds ratio; CI: Confidence Interval. Results are expressed as AOR and 95% confidence interval for AOR.
Hosmer and Lemshow goodness of fit test for mean temperature (chi-square value = 12.72, df = 8 and *P* value = .122).
Hosmer and Lemshow goodness of fit test for relative humidity (chi-square value = 13.8, df = 8 and *P* value = .087).
Reference category is indicated by OR = 1.
*AOR of IS over ICH.
†*P* value has been calculated using Wald test statistics.

Table 5. *Adjusted odds ratio and 95% confidence intervals using multiple binary logistic regression model to examine the impact of 1 unit increase in the atmospheric pressure and solar radiation on stroke subtype (IS over ICH) after adjusting for demographics and potential risk factors*

Factor	Atmospheric pressure AOR* (95% CI)	*P* value †	Solar radiation AOR* (95% CI)	*P* value †
IS	0.977 (0.966-0.989)	<0.001	1.271 (1.025-1.576)	.029
Age (In years)	1.020 (1.013-1.028)	<0.001	1.015 (1.006-1.024)	.002
Gender(Male)	0.796 (0.622-1.020)	0.071	0.779 (0.576-1.054)	.105
Presence of risk factors history				
• HTN	0.407 (0.324-0.511)	<0.001	0.405 (0.308-0.533)	<.001
• DM	2.423 (2.001-2.953)	<0.001	2.521 (2.003-3.172)	<.001
• Dyslipidemia	2.290 (1.905-2.753)	<0.001	2.217 (1.776-2.767)	<.001
• AF on ADM	3.546 (2.086-6.029)	<0.001	3.229 (1.781-5.856)	<.001
• Smoking	3.590 (2.730-4.720)	<0.001	3.133 (2.296-4.275)	<.001

Abbreviations: AOR: Adjusted odds ratio; CI: Confidence Interval. Results are expressed as AOR and 95% confidence interval for AOR.
Reference category is indicated by OR = 1.
Hosmer and Lemshow goodness of fit test for atmospheric pressure (chi-square value = 9.45, df = 8 and *P* value = .306).
Hosmer and Lemshow goodness of fit test for solar radiation (chi-square value = 14.67, df = 8 and *P* value = .07).
*AOR of IS over ICH.
†*P* value has been calculated using Wald test statistics.

Previous studies have reported conflicting results on the effects of increasing ambient temperatures on the incidence of stroke.[16,17] While some large studies reveal an increase in stroke rates during summer-autumn months, other studies showing an increase in stroke in the winter months. Our study is in agreement with a recent systematic review and meta-analysis, showing an increase in temperatures acting as a risk factor for IS, while it had a protective effect for ICH.[16] The increased risk was evident in both sexes and seemed to be most evident in patients over age 65 years. A similar observation has been reported in the coronary ischemia study, sharing similar risk factors to stroke.[18] An increase in ambient temperature, especially if extreme can increase stroke risk via multiple mechanisms, directly and indirectly, including changes in blood viscosity and hemoconcentration.[1,2] Although we carefully look for a number of physiological parameters that may suggest dehydration as a potential mechanism, all of these including hematocrit, serum creatinine, and blood urea nitrogen were not different between the summer or winter months.

The beneficial effects of sunlight on vitamin D in lowering blood pressure in hypertensive patients, decreasing the incidence and severity of cardiovascular disorders, type 2 DM, metabolic syndrome, and a potential anti−inflammatory are well known.[19,20] Due to the extremely hot temperatures, most people in Qatar stay indoors leading to low vitamin D levels in approximately 90% of the population.[21] However excessive daily exposure to solar radiation is also known to increase the risk of atherosclerosis and stroke[22] as observed in the current study.

The mechanisms underlying seasonal variation of strokes are not fully understood. In the absence of dehydration and lack of variation in the stroke risk factors, probable explanations for seasonal variation in stroke incidence include air quality and temperature interaction. There is a strong correlation between climate and air quality particularly for ozone levels that are directly driven by weather. The ozone-generating photochemical reactions of air pollutants require high temperatures and bright sunshine, conditions typical of desert summer months.[23] Moreover, our data comes from a desert region known to be the source of dust storms driven by hot weather affecting air quality, in particular PM10 and coarse particulate (PM2.5-10) levels.[24,25] The deficiency of vitamin D, hot temperatures and air quality might have a synergistic effect leading to higher ISs in summer months in our data.

We observed a higher rate of ICH in the winter months as reported by others.[7,26] Cold exposure is thought to increase blood pressure by activating the sympathetic nervous system.[27] In the current study, we neither observed seasonal change in blood pressure nor was the relation between ICH and temperature, though statistically significant, a strong one. This is likely related to the milder winters in the Arabian Peninsula. In agreement with previous studies, we also observed that ICH was related to higher atmospheric pressure and that IS to lower air pressure.[28-31] Moreover, ICH was associated with relative humidity. Variation in atmospheric pressure may influence vessel walls and their endothelial function through endogenous inflammatory mechanisms.[32]

Although the relationship between meteorological factors and strokes has long been suggested, considerable uncertainty exists regarding the validity of this relationship. A number of studies have obtained different results for seasonal variations in stroke. Most of the studies performed in countries with cold or temperate climates[7,33,34,8] report different results compared to hot weather.[13,35] This inconsistency may in part be due to extremes of temperatures suggests that exposure to extreme temperatures, whether cold or hot, may increase the risk of stroke. In addition, the regional studies may highlight a distinct meteorological pattern that is locally relevant, but not applicable to other regions. Moreover, it is reasonable to assume that acclimation plays a significant role in modulating the relationship between a patient and their environment[36] as shown by the heatwaves in Europe, highlighted the susceptibility of patients with respiratory and cardiovascular diseases.[37] These factors limit our ability to make cross-study comparisons.

We are aware of some limitations of our study. The study has all the limitation that a retrospective observational study may have. We did not study the concomitant changes in other factors such as air pollution, and diet that could have influenced the stroke risk.[10] However, variation in temperature has been considered the most important factor.[38] This study focuses on 1 center. In the study area, emergency stroke service is available for all the residents, round-the-clock and free of charge. Being the single largest hospital in the country with acute stroke treatment [advanced imaging, thrombolysis, thrombectomy, and rehabilitation] virtually all the stroke patients are admitted to this hospital. These unique characteristics of the health care in Qatar minimized the influence of referral bias in our database. Our study covers a relatively small catchment area in the global context. Since weather in the Arabian Peninsula is similar, our results will be applicable to the region and other areas with similar extreme weather patterns.

In summary, our study reveals seasonal variation in the occurrence of stroke and association with meteorological factors, in an extremely hot climate. The risk for the development of IS was higher than ICH during the summer months when the average 24-hour temperatures can be very high. During the summer months, particularly when heat waves are predicted, the added risk for stroke should be disseminated to both the people and their health care providers so preventive measures can be initiated. Attention should be devoted to air conditioning and adequate consumption of liquids. Due to high prevalence of vitamin D deficiency food fortification with will be needed.

Compliance With Ethical Standards

The study adhered to the tenets of the declaration of Helsinki and was approved by the Institutional Review Board of Hamad Medical Corporation, Qatar [MRC-01-17-048].

Conflict of Interest

The Authors declare that there is no conflict of interest.

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Supplementary Materials

Supplementary material associated with this article can be found in the online version at doi:10.1016/j.jstrokecerebrovasdis.2019.05.032.

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