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ORIGINAL ARTICLE
Epidemiology

Full Moon and Out-of-Hospital Cardiac Arrest in Japan
— Population-Based, Double-Controlled Case Series Analysis —

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Background: It is commonly believed that a full moon affects human behavior or the occurrence and outcome of various diseases; thus, the occurrence of out-of-hospital cardiac arrest (OHCA) might increase during full moon nights.

Methods and Results: This nationwide, population-based observational study consecutively enrolled OHCA patients in Japan with attempted resuscitation between 2005 and 2016. The primary outcome measure was the occurrence of OHCA. Based on the double-control method, assuming Poisson sampling, we evaluated the average number of OHCA events that occurred on full moon nights compared with that which occurred on control nights, which included events that occurred on the same calendar days 1 week before and after the full moon nights. A total of 29,552 OHCA that occurred on 148 full moon nights and 58,707 OHCA that occurred on 296 control nights were eligible for analysis. The occurrence of OHCA did not differ between full moon and control nights (199.7 vs. 198.3 per night; relative risk [RR], 1.007; 95% CI: 0.993–1.021). On subgroup analysis, compared with control nights, the RR of OHCA occurrence were 1.013 (95% CI: 0.994–1.032, P=0.166) and 0.998 (95% CI: 0.977–1.020, P=0.866) for cardiac and non-cardiac origins, respectively.

Conclusions: In this population, there was no significant difference in OHCA occurrence between full moon and control nights.

Key Words: Full moon; Occurrence; Out-of-hospital cardiac arrest; Registry

It is commonly believed that the full moon affects human behavior and the occurrence and outcome of various diseases.[1–4] Previous studies have suggested that lunar phases might be associated with an increased incident risk of cardiovascular diseases such as acute myocardial infarction (AMI)[3] or atrial fibrillation.[5] These cardiovascular diseases could be the cause of out-of-hospital cardiac arrest (OHCA).[6] Other preceding studies also demonstrated that the moon affects humans as follows: the gravitational forces would cause cyclic fluid shifts between body compartments and thereby trigger emotional disturbances, suicides and aggressive behavior in predisposed individuals, as stipulated in the theory of biological tides.[7,8] Other theories have considered moon-related variations in electromagnetic fields,[9] weather[10] and illumination[11,12] as potential factors that could affect humans behavior and cause adverse health effects. Considering these findings, OHCA occurrence might increase during full moon nights.

The occurrence of OHCA has been associated with calendar patterns such as circadian or weekly variability,[13,14] and a retrospective regional study demonstrated that lunar phases were not related to the occurrence of sudden cardiac death.[15] The association between full moon and OHCA occurrence, however, has not been sufficiently investigated worldwide.

The All-Japan Utstein Registry is a nationwide population-based observation database that has collected information on >1.4 million OHCA patients in Japan since 2005.[16] We used this database to evaluate the difference in OHCA occurrence between full moon and control nights.

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Our hypothesis was that the occurrence of OHCA might increase during full moon nights.

Methods

Study Design and Setting

The All-Japan Utstein Registry of the Fire and Disaster Management Agency (FDMA) is a nationwide population-based OHCA registry based on the international Utstein-style data collection.[17–19] This study enrolled all patients with OHCA who were transported to medical institutions between 2005 and 2016. Details of the All-Japan Utstein Registry, including the data collection and quality control, as well as that of the Japanese emergency medical service (EMS) system, have been described previously.[19]

OHCA was defined as the cessation of cardiac mechanical activity, as confirmed by the absence of circulation signs.[17,18] The origin of OHCA was classified into 2 groups: cardiac origin or non-cardiac origin. Cardiac origins were defined as anything other than non-cardiac origins; non-cardiac origins of OHCA were defined as cerebrovascular disease; respiratory disease; malignant tumor; external causes including asphyxia, drug overdose, drowning, hanging, trauma; or any other non-cardiac origins, based on the Utstein-style guidelines for reporting OHCA.[17,18] Diagnoses of OHCA caused by cardiac and non-cardiac origins were made clinically by the corresponding physician in charge within the EMS personnel.[19]

EMS Systems in Japan

Japan had a population of approximately 127 million in 2016. The EMS is provided by the regional governments through each fire department. There were 732 fire departments with respective dispatch centers in 2016.[16] Usually, an ambulance has 3 emergency providers as crew, including at least 1 emergency life-saving technician (ELST), who are trained to insert an i.v. line, place an adjunct airway, and conduct a semi-automated external defibrillator. Specially trained ELST are also able to insert an endotracheal tube and administer i.v. epinephrine. Public-access defibrillation is legally permitted in Japan. According to the Japanese cardiopulmonary resuscitation (CPR) guidelines, EMS providers conduct CPR for OHCA patients.[6]

Do-not-resuscitate orders or living wills are generally not accepted in Japan, and EMS providers are not permitted to terminate resuscitation in the field. Therefore, most patients with OHCA who were treated by EMS personnel were transported to hospital and were registered in this cohort, excluding cases of decapitation, incineration, decomposition, rigor mortis, or dependent cyanosis.

Data Collection and Quality Control

Based on the Utstein-style guidelines for reporting OHCA,[17,18] data were collected using a specific form that included details on date, patient age, patient sex, witness status, first recorded cardiac rhythm, time course of resuscitation, bystander-initiated CPR, public-access automated external defibrillator (AED) shock, i.v. epinephrine, and advanced airway management.

The data sheet was completed by EMS personnel with the physicians in charge of OHCA patients and the data were unified into the registry system on the FDMA database server. They were logically checked by the computer system and were confirmed by the working group. If the data form was not complete, the FDMA returned it to the respective fire station for completion.

Key Group Definitions

This study defined the full moon as the 1 night each month when the entire facing surface was illuminated, as viewed from Earth.[2] On rare occasions, a month had 2 full moons; in such cases, we included both appearances (e.g., 1 and 30 January 2010).[2] The calendar patterns of lunar phases for each year during the study period were obtained from a website.[20,21] Based on a previous study, we used the double-control method,[2] which allows for near-perfect temporal symmetry for cases and controls and could not create a time imbalance inside each pair,[22] in this study to assess the difference in OHCA occurrences during full moon and control nights. In accordance with this method, the following 2 groups were identified: the exposure group, which consisted of OHCA that occurred on full moon nights; and the control group, which consisted of OHCA that occurred during the same calendar days in the 1 week before and after the full moon nights. For example, the full moon on Friday, 20 November 2015, was matched to the control dates of Friday, 13 November and Friday, 27 November 2015. This matching ensured identical time intervals for all comparisons and directly controlled for weekday, seasonal, and yearly trends.[2] In addition, we defined night-time as the interval between 4 p.m. and 8 a.m. (16 hours), in order to include all hours when the full moon might be visible over Japan (including the relevant hours of dusk and dawn).[2]

Main Outcome Measure

The primary outcome measure was the occurrence of OHCA.

Statistical Analysis

Main analysis compared the average number of OHCA on full moon nights with control nights.[2,22] We assumed that the number of OHCA at the i-th full moon night (case) followed a Poisson distribution. The number of OHCA on the corresponding night 1 week before and that after the full moon night (control) were assumed to follow the common Poisson distribution. We assumed that the Poisson intensity of the case night and that of the control nights shared a matching-specific effect, which controlled for the calendar effect.

To make inferences on the average number (intensity) of OHCA, we utilized a method that is free from night-specific effects and thus must be more stable than the maximum likelihood method. Details of the method are given as follows. Suppose we have n full moon nights (case). Let X_i be the number of OHCA at the i-th full noon night, and Y_i and Z_i are that at the date 1 week before and after the full noon night, respectively (controls). We assume that X_i follows the Poisson distribution with the intensity $\lambda_1\theta_i$, and Y_i and Z_i follow the Poisson distribution with the intensity of $\lambda_2\theta_i$. Here, θ_i represents the night-specific effect, which is shared among the matched pairs. Let $X=\Sigma_i X_i$, $Y=\Sigma_i Y_i$ and $Z=\Sigma_i Z_i$. From the reproducibility of the Poisson distribution, X, Y, and Z follow the Poisson distribution with the intensity $\lambda_1\Sigma_i\theta_i$, $\lambda_2\Sigma_i\theta_i$ and $\lambda_2\Sigma_i\theta_i$, respectively. The log-relative intensity $\log(\lambda_1/\lambda_2)=\log\{\lambda_1\Sigma_i\theta_i/(\lambda_2\Sigma_i\theta_i)\}$ is estimated by $\hat{\Delta}_y=\log(X/Y)$. Similarly, it can be estimated by $\hat{\Delta}_z=\log(X/Z)$. Then, one can consider a class of consistent estimators $\hat{\Delta}=\alpha\hat{\Delta}_y+\beta\hat{\Delta}_z=\log X-(\alpha\log Y+\beta\log Z)$, where α and β are constants satisfying $\alpha+\beta=1$, for estimation of $\log(\lambda_1/\lambda_2)$.

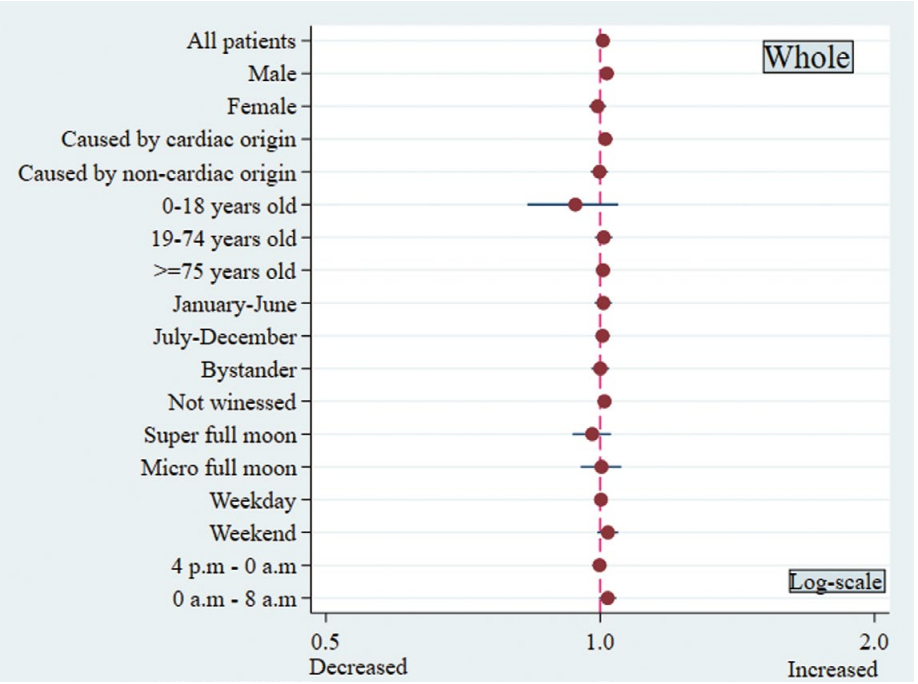

Figure 1. Relative risk of out-of-hospital cardiac arrest on full moon nights.

Table 1. Relative Risk of OHCA on Full Moon Nights

	Full moon nights	Control nights	RR	95% CI	P-value
All patients	29,552	58,707	1.007	0.993–1.021	0.345
Subgroup					
Sex					
Male	16,971	33,381	1.017	0.998–1.036	0.077
Female	12,581	25,326	0.994	0.972–1.015	0.552
Origin of OHCA					
Cardiac	17,233	34,023	1.013	0.994–1.032	0.166
Non-cardiac	12,319	24,684	0.998	0.977–1.020	0.866
Age group (years)					
0–18	432	920	0.939	0.832–1.047	0.282
19–74	11,979	23,745	1.009	0.987–1.031	0.425
≥75	17,141	34,042	1.007	0.989–1.026	0.453
Season					
January–June	12,457	24,717	1.008	0.986–1.030	0.470
July–December	17,095	33,990	1.006	0.987–1.024	0.532
Witness status					
Bystanders	11,520	23,033	1.000	0.978–1.023	0.979
Not witnessed	18,032	35,674	1.011	0.993–1.029	0.234
Type of full moon					
Super full moon	2,403	4,905	0.980	0.932–1.028	0.418
Micro full moon	2,174	4,334	1.003	0.952–1.055	0.902
Time of day					
Weekday	21,323	42,565	1.002	0.985–1.018	0.819
Weekend	8,229	16,142	1.020	0.993–1.047	0.151
Night-time period					
4 p.m.–0 a.m.	17,409	34,877	0.998	0.980–1.016	0.855
0 a.m.–8 a.m.	12,143	23,830	1.019	0.997–1.041	0.089

OHCA, out-of-hospital cardiac arrest.

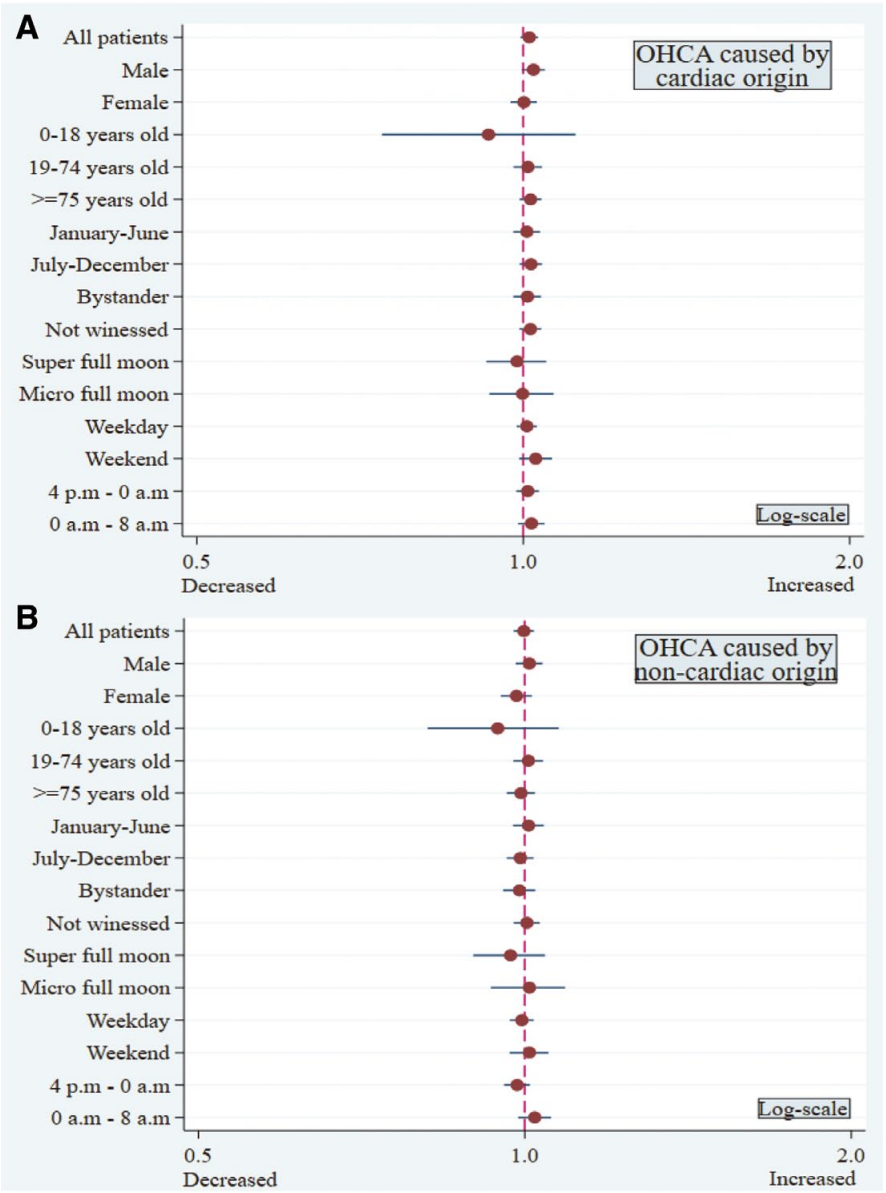

Figure 2. Relative risk of out-of-hospital cardiac arrest (OHCA) on full moon nights according to (**A**) cardiac and (**B**) non-cardiac origin.

Noting that the variance of the log-transformed Poisson variable (say log X) is given approximately by the inverse of the intensity ($1/(\lambda_1\Sigma_i\theta_i)$) if the intensity is large,[17] one can show that $\alpha=\beta=1/2$ makes the asymptotic variance of $\hat{\Delta}$, say $V(\hat{\Delta})$, smallest, and $V(\hat{\Delta})$ is estimated by

$$\hat{V}(\hat{\Delta}) = \frac{1}{X} + \frac{1}{Y+Z}$$

and then we define a test statistic,

$$W = \frac{\hat{\Delta}}{\sqrt{\hat{V}(\hat{\Delta})}} = \frac{\log(X) - \frac{\{\log(Y)+\log(Z)\}}{2}}{\sqrt{\frac{1}{X} + \frac{1}{Y+Z}}}$$

which is approximately normally distributed. Thus the P-value is given by $2\{1-\varphi(|W|)\}$, where $\varphi(\cdot)$ is the cumulative distribution function of the standard normal distribution.

A subgroup analysis was conducted according to the origin of OHCA (cardiac and non-cardiac origins). Stratified analyses accounted for characteristics of sex (male, female), age group (0–18 years old, 19–74 years old, ≥75 years old), season (January–June, July–December), witness status (bystanders, not witnessed), type of full moon (super full moon, micro full moon), time of day (weekday, weekend), and night-time period (4 p.m.–0 a.m., 0 a.m.–8 a.m.). The type of full moon was defined as follows: super full moon, when a full moon occurs during the moon's closest approach to earth in a calendar year; and micro full moon, when a full moon coincides with apogee (the point in the

Table 2. Relative Risk of OHCA on Full Moon Nights vs. OHCA Origin

	Full moon nights	Control nights	RR	95% CI	P-value
Cardiac origin					
All patients	17,233	34,023	1.013	0.994–1.032	0.166
Subgroup					
Sex					
Male	9,828	19,233	1.022	0.997–1.047	0.079
Female	7,405	14,790	1.001	0.973–1.029	0.923
Age group (years)					
0–18	137	295	0.929	0.741–1.117	0.476
19–74	6,240	12,356	1.010	0.979–1.041	0.520
≥75	10,856	21,372	1.016	0.992–1.039	0.180
Season					
January–June	7,081	14,052	1.008	0.979–1.037	0.591
July–December	10,152	19,971	1.017	0.992–1.041	0.175
Witness status					
Bystanders	6,650	13,181	1.009	0.979–1.039	0.550
Not witnessed	10,583	20,842	1.016	0.992–1.039	0.196
Type of full moon					
Super full moon	1,413	2,864	0.987	0.924–1.050	0.691
Micro full moon	1,242	2,488	0.999	0.931–1.067	0.967
Time of day					
Weekday	12,455	24,718	1.008	0.986–1.029	0.481
Holiday	4,778	9,305	1.027	0.991–1.063	0.135
Night-time period					
4 p.m.–0 a.m.	9,870	19,552	1.010	0.985–1.034	0.437
0 a.m.–8 a.m.	7,363	14,471	1.018	0.989–1.046	0.222
Non-cardiac origin					
All patients	12,319	24,684	0.998	0.977–1.020	0.866
Subgroup					
Sex					
Male	7,143	14,148	1.010	0.981–1.038	0.504
Female	5,176	10,536	0.983	0.950–1.015	0.300
Age group (years)					
0–18	295	625	0.944	0.813–1.075	0.415
19–74	5,739	11,389	1.008	0.976–1.040	0.630
≥75	6,285	12,670	0.992	0.962–1.022	0.608
Season					
January–June	5,376	10,665	1.008	0.975–1.041	0.626
July–December	6,943	14,019	0.991	0.962–1.019	0.516
Witness status					
Bystanders	4,870	9,852	0.989	0.955–1.023	0.514
Not witnessed	7,449	14,832	1.004	0.976–1.032	0.754
Type of full moon					
Super full moon	990	2,041	0.970	0.896–1.044	0.434
Micro full moon	932	1,846	1.010	0.930–1.089	0.807
Time of day					
Weekday	8,868	17,847	0.994	0.969–1.019	0.633
Weekend	3,451	6,837	1.010	0.969–1.051	0.638
Night-time period					
4 p.m.–0 a.m.	7,539	15,325	0.984	0.957–1.011	0.248
0 a.m.–8 a.m.	4,780	9,359	1.021	0.986–1.057	0.232

OHCA, out-of-hospital cardiac arrest.

moon's orbit farthest away from the Earth In a calendar year).[20,21] In a sensitivity analysis, we also compared the average number of OHCA on full moon nights vs. new moon nights.

All of the tests were 2-tailed, and P<0.05 was considered statistically significant. Statistical analysis was carried out using R version 3.5.0 (The R Foundation for Statistical Computing) and STATA version 14.0MP (Stata Corp., College Station, TX, USA).

Ethics

The study was approved by the institutional review board of the Ethics Committee of the Osaka University School of Medicine. The requirement for written informed consent was waived, and researchers used and analyzed anonymous data without individual information.

Results

A total of 1,423,398 OHCA occurred during the study period. Of these, 143,865 OHCA occurred during 444 full moon and control nights (48,074 OHCA on 148 full moon nights and 95,791 OHCA on 296 control nights) in Japan. OHCA cases without information on age (n=13) and cause of origin (n=1) and that occurred in the daytime (from 8:00 am to 3:59 pm) (n=55,592) were excluded. Finally, 88,259 eligible OHCA were analyzed: 29,552 on full moon nights (199.7 per night); and 58,707 OHCA on control nights (198.3 per night).

Figure 1, **Table 1** show the RR of OHCA occurrence on full moon nights in all patients. Compared with control nights, the RR of full moon nights was 1.007 (95% CI: 0.993–1.021, P=0.345). On stratified analysis, RR was 0.980 (95% CI: 0.932–1.028, P=0.418) on super full moon nights and 1.003 (95% CI: 0.952–1.055, P=0.902) on micro full moon nights. Other stratified analyses had similar results, and no significant differences were observed in the OHCA occurrence between full moon and control nights.

Figure 2, **Table 2** show the RR of OHCA occurrence on full moon nights by the origin of OHCA. Compared with control nights, the RR of OHCA occurrence was 1.013 (95% CI: 0.994–1.032, P=0.166) for OHCA caused by cardiac origin, and 0.998 (95% CI: 0.977–1.020, P=0.866) for OHCA caused by non-cardiac origin. On stratified analysis, the RR in each group were almost 1.0, irrespective of the origin of OHCA. In addition, compared with new moon nights, the RR of full moon nights was 1.006 (95% CI: 0.990–1.022, P=0.456) for all patients, 1.018 (95% CI: 0.996–1.040, P=0.100) for OHCA caused by cardiac origin, and 0.990 (95% CI: 0.965–1.015, P=0.434) for OHCA caused by non-cardiac origin (**Supplementary Table**).

Discussion

Contrary to the present hypothesis but consistent with previous reports, the present study using data from a nationwide population-based OHCA registry in Japan found no significant difference in OHCA occurrence between full moon and control nights. The Japanese nationwide population-based registry enabled us to evaluate the impact of full moon on OHCA occurrence in a real-world setting and this study used a unique statistical method to provide helpful information to improve resuscitation practice.

The present results underscore the lack of significant difference in OHCA occurrence between full moon and control nights in Japan, a relationship that remained consistent on subgroup analysis. The effect of the full moon on human behavior or on the occurrence and outcome of various diseases is a decades-long controversy. Inconsistent results have been reported regarding the full moon night being positively or negatively associated with the risk of various medical conditions such as cardiovascular disease,[15] traffic accidents,[2] birth,[23] surgery,[4] sleep duration,[1] or even suicide and crime.[24,25] For example, the MONICA/KORA Registry recently suggested that the moon phase did not have any apparent association with the occurrence of AMI.[26] Previous studies explained the association of a full moon with medical conditions due to exposure levels of moonlight,[1] stress,[26] or hormones.[1,26] Furthermore, the gravitational forces would cause cyclic fluid shifts between body compartments and thereby trigger emotional disturbances, suicides and aggressive behavior in predisposed individuals, as stipulated in the theory of biological tides.[7,8] Other theories have considered moon-related variations in electromagnetic fields,[9] weather[10] and illumination[11,12] as potential factors that could affect human behaviors and cause adverse health effects. Thus, on the day of the full moon, the incidence of disease increased, but few cases might result in OHCA. Therefore, there would be no difference between full moon and control nights in the present patients. Further investigation on the association between full moon and OHCA, however, is needed.

This study has some strengths. First, we used a double-control method[22] to assess the association between full moon and OHCA occurrence. To confirm this association, the definition of the control group was most important. While most previous studies used other lunar phases such as the new moon,[15] the recently developed double-control method has been used to assess the association between calendar pattern (e.g., lunar phases[2] or academic meetings[27]) and medical conditions; this method is considered robust, because it directly controls for calendar bias and indirectly reduces the risk of confounding due to differences in characteristics between groups.[22] A second strength was the clear and concise Utstein-style guidelines for reporting OHCA.[17,18] The uniform data collection, consistent definitions, and large sample size in the population-based cohort study were intended to minimize these potential sources of bias.

If a full moon affects the occurrence of OHCA, greater medical resource allocation during full moon nights should be considered, given that circadian and weekly variations in the performance of EMS systems are an important issue in OHCA treatment.[13,14] The present results, however, indicate that there is no need to allocate medical resources for OHCA patients based on lunar phase in Japan. Verification of the association between lunar phase and the occurrence and outcome of disease will continue worldwide because so many people believe in myths associated with a full moon.

The present study has some limitations. First, the extent of cloud cover, prevailing weather, and moon visibility were unknown.[2] Second, we defined night-time as the same time range (4 p.m.–8 a.m.) for the whole year, although the time of moonrise and moonset changed every day. Third, this study using the double-control method did not consider the denominator because this method treated only data of cases. Fourth, the category of OHCA caused by cardiac origin is a diagnosis by exclusion (i.e., the diagnosis is made when there is no evidence of a non-cardiac cause), in

accordance with the Utstein-style international guidelines for OHCA data reporting.[17,18] Finally, the present results may not be generalized to other countries because this study was carried out in Japan.

Conclusions

In this population, there was no significant difference in the occurrence of OHCA between full moon and control nights. Other epidemiological studies on the impact of a full moon on OHCA occurrence are required to confirm the present results.

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Disclosures

The authors declare no conflicts of interest.

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Supplementary Files

Please find supplementary file(s);
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