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Effect of weather variables on the incidence of trauma

A retrospective study at a single tertiary hospital center for 4 years

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Abstract

The occurrence of trauma is associated with various factors, including weather. We aimed to elucidate the relationship between local weather factors and the incidence of trauma to effectively manage and treat patients in a community setting. A retrospective study was conducted at a single center from January 2016 to December 2019. The study participants were trauma patients in the Cheongju area where the regional trauma center is located. Weather data including average daily temperature (°C), rainfall duration (hours), amount of rainfall (mm), average relative humidity (%), wind speed (m/s), and total sunlight hours per day were collected. One-way analysis of variance, correlation analysis, and linear regression analysis were performed. The average age of the participants (n = 3352) was 52.69 years. As regards seasonal difference in the incidence of trauma, there were more patients in spring than in winter (2.42/day vs 2.06/day, $P = .05$). The highest number of average daily trauma incidents occurred from April to June, and the difference between this value and that from January to February was significant ($F = 2.20$, $P = .01$). According to the distributed lag nonlinear model (DLnM), the relative risk is greater than 1 when the mean temperature is high (>15°C) compared to when the temperature is low (<15°C). The trauma patient prevalence was the highest at high wind speed (4.5 m/s). When the total amount of sunlight was long (>Ref. 8 hours), the trauma patient prevalence was relatively higher than the median value (lag = 0). DLnM analysis results showed that the relative risk of trauma patients increased as the amount of precipitation increased, and the incidence of trauma increased when the relative humidity was 40% to 50%. Multiple linear regression analysis revealed that high average daily temperatures and long average daily total sunlight hours resulted in an increased incidence of trauma ($F = 6.605$, $P < .001$). An increase in temperature, an increase in the daily sunlight hours, an increase in rainfall, high wind speed, and relative humidity of 40% to 50% are associated with a relatively high risk of trauma.

Abbreviation: DLnM = distributed lag non-linear model.

Keywords: emergency medical services, relationship, trauma, weather

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1. Introduction

According to the Korea National Statistical Office, more than five million patients are admitted to the emergency unit every year in Korea, with trauma being one of the main reasons. From 2014 to 2018, 27.03% admissions to the emergency room were related to trauma.[1] The initial management of trauma in the emergency room is critical and expensive because of the utilization of a tremendous number of medical resources, often more than those used for other diseases. Further, trauma is one of the most important global healthcare problems.[2] The importance of trauma management has recently been recognized in South Korea; therefore, regional trauma centers have been established to respond quickly and efficiently to and treat trauma cases.

Trauma can occur at any time, any place, during day-to-day activities, and often requires emergency medical treatment. Predicting the incidence of trauma is advantageous for planning emergency treatment and managing hospital rooms and medical resources.[3] However, accurate prediction is challenging because various factors, such as main activity time, day of the week, and life pattern, interact with each other along with the changes in season and weather.[2]

Although South Korea has a relatively small area of 99,720 km^2, it is in the mid-latitude temperate climate zone with four distinct seasons, making it geographically suited to study the relationship between the incidence of trauma and weather.

Several studies have reported that weather and seasonal changes are related to the incidence of trauma.[4] Some studies have shown that the incidence of trauma is higher in warm weather than in cold weather, especially in cases of pediatric trauma.[5] Another study showed that the incidence of trauma in young men tends to increase as the temperature rises during spring and summer.[6] Although the relationship between temperature and the incidence of trauma has been shown by various studies, the association of the incidence of trauma with other weather-related factors, such as insolation, humidity, rainfall, and wind speed, is yet to be determined. Despite similar weather factors, contradicting results were obtained depending on the region in which the study was conducted.[4] Therefore, to efficiently manage and treat trauma patients within a community, studies on the relationship between weather and the incidence of trauma should be conducted in the area where the regional trauma center is located. Hence, we aimed to assess the relationship between local weather factors and the incidence of trauma in patients who were admitted to the trauma center in the central region of South Korea.

2. Methods

2.1. Patients and data collection

Based on the Korean Trauma Data Bank, we enrolled trauma patients who were admitted to the regional trauma center of the Chungbuk National University Hospital from January 2016 to December 2019. A total of 4665 trauma cases were recorded in 18 regions within this area. However, because weather conditions vary from city to city, only those patients who visited the trauma center located in Cheongju were included in the study to ensure consistency of weather variables. We excluded cases with unclear trauma location or time. Therefore, only 3352 cases were finally included. Patient data were collected retrospectively from the electronic medical records of the hospital. Meteorological factors such as average daily temperature (°C), rainfall duration (hours), amount of rainfall (mm), average relative humidity (%), average wind speed (m/s), and total sunlight hours per day in the study region were collected from the Korea Meteorological Agency using the Automated Surface Observing System.

The study protocol conforms to the ethical guidelines of the 1975 Declaration of Helsinki as reflected by a priori approval by the institution's human research committee.

2.2. Definition

Trauma was defined as any physical damage from external forces due to accidents, falls, hits, or other reasons. Fall height higher than the patient's height was defined as "fall down" and lower that the height was defined as "rolling/slip down." Traffic accidents were classified according to the persons and vehicles involved: pedestrians, drivers, passengers, motorcycles, bicycles, and other means of transportation. Regarding seasons, spring was defined as the time from March to May, summer from June to August, autumn from September to November, and winter from December to February.

2.3. Statistical analysis

Correlation analysis was performed for each weather variable and the average number of patients per day to determine the correlation between the incidence of trauma and the weather. One-way analysis of variance was performed to examine the monthly changes in each weather variable and the average number of patients admitted per day. Post-hoc analysis was conducted to check the monthly difference in each variable. Assessment of correlation between time series data of the number of trauma patients for each weather variable revealed no strong correlation in the same time lag; thus, analysis was possible with a distributed lag nonlinear model (DLnM). Lag = 30 was used to compare the difference in prevalence according to the monthly period. In addition, the overall cumulative delay effect for each weather-related variable was checked through DLnM reduction. All two-tailed P values <.05 were considered significant. Statistical analyses were performed using IBM SPSS Statistics for Windows, version 23.0 (IBM Corp., Armonk, NY) and R (R version 4.1.0)

3. Results

The characteristics of the trauma patients who were admitted to the emergency room from January 2016 to December 2019 are shown in Table 1. A total of 3352 trauma patients (2132 men, 63.6% and 1220 women, 36.4%) in Cheongju were admitted to the regional trauma center; the average age was 52.69 years ± 22.98, and the average injury severity score was 10.02 ± 8.92. Rolling/slip down was the most common reason for trauma (n = 815, 24.3%), followed by fall down (n = 625, 18.6%). Regarding the seasonal difference in the incidence of trauma, more patients visited in spring than in winter (2.42/day vs 2.06/day, P = .05). Further, in the analysis by day of the week, Saturday showed a higher incidence of trauma patient admissions than Sunday (2.60/day vs 2.06/day, P = .021) (Table 2).

We analyzed the monthly weather variables and average daily number of patients admitted using one-way analysis of variance; the results are shown in Figures 1 and 2 and Table 3. The average daily number of trauma patients who were admitted to the emergency room was the highest (2.60) in May (Fig. 1). The highest number of average daily trauma incidents occurred from April to June, and the difference between this value and that from

Table 1

Characteristics of the study participants who were admitted to the emergency room.

Total patients, N	3352
Age, yr*	52.69 (22.98)
Range	1–99
ISS*	10.02 (8.92)
Range	1–75
Sex, N (%)	
Men	2132 (63.6%)
Women	1220 (36.4%)
Injury mechanism, N (%)	
Pedestrian TA	214 (6.4%)
Driver TA	375 (11.2%)
Passenger TA	96 (2.9%)
Motorcycle TA	323 (9.6%)
Bicycle TA	142 (4.2%)
Fall down	625 (18.6%)
Rolling/slip down	815 (24.3%)
Other motor vehicle TA	226 (6.7%)
Penetrating injury	137 (4.1%)
Others	399 (11.9%)

* Average (standard deviation).

Table 2

Average number of trauma patient emergency room visits per day.

	Emergency room visits per day*	*P* value
Season, N (%)††		.005
Spring, 891 (26.6%)	2.42 (1.60)	
Summer, 885 (26.4%)	2.40 (1.54)	
Autumn, 835 (24.9%)	2.30 (1.51)	
Winter, 741 (22.1%)	2.06 (1.53)	
Day of the week, N (%)†		.021
Monday, 452 (13.5%)	2.17 (1.58)	
Tuesday, 490 (14.6%)	2.35 (1.43)	
Wednesday, 473 (14.1%)	2.27 (1.46)	
Thursday, 483 (14.4%)	2.32 (1.65)	
Friday, 480 (14.3%)	2.30 (1.63)	
Saturday, 544 (16.2%)	2.60 (1.65)	
Sunday, 430 (12.8%)	2.06 (1.41)	

* Average number of patient (standard deviation).
† $P < .05$.
†† $P < .01$.

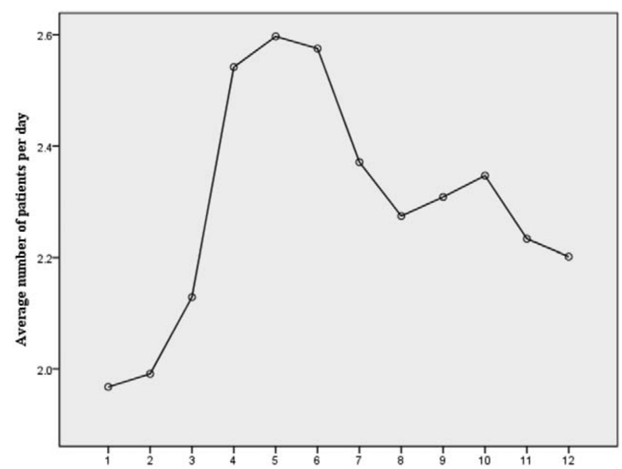

Figure 1. Average number of trauma patients per day for each month.

January to February was significant ($F=2.20$, $P=.01$) (Table 3). The average daily temperature was the lowest in January (−1.40°C) but continued to rise until August (27.54°C) and then dropped again from September (22.09°C) ($F=1203.09$, $P < .001$). The average daily rainfall duration was the highest in July (3.41 hours), and post-hoc analysis showed that this value was significantly higher than those of January, February, March, June, October, November, and December ($F=2.01$, $P=.02$).

The average daily rainfall was significantly higher in July than in other months (13.22 mm) ($F=8.91$, $P < .001$). The average daily relative humidity was also highest in July (71.36%), whereas it was relatively low in January (56.79%) and May (51.62%) ($F=38.33$, $P < .001$). The average daily wind speed was the highest in April (1.76 m/s) and August (1.68 m/s) and the lowest in November (1.18 m/s) ($F=14.70$, $P < .001$). The total number of hours of sunshine was the highest in May (9.19 hours), followed by April (7.74 hours) and June (8.17 hours). Post-hoc analysis also showed that the total number of hours of sunshine was the highest in May compared with other months (February, March, April, June, and August; $F=9.02$, $P < .001$) (Fig. 2).

For the DLnM analysis of the average temperature, we set the minimum (−13°C), maximum (33°C), and specific values (0, 20, 30°C) to determine the lag-response (Reference Criteria = Median [15°C]). DLnM analysis of mean temperature showed that for low temperatures (<15°C), the relative risk of trauma prevalence at lag = 0 was low but increasing over time. However, the relative risk was close to 1. Therefore, the risk of having trauma patients decreased with the passage of exposure time. When the average temperature was high (>15°C), compared to when it was low (<15°C), the relative risk was greater than 1 in the absence of a lag-response. However, as the lag increased, the relative risk of having trauma patients moved close to 1. Therefore, the risk decreased with the passage of exposure time (Fig. 3, Supplementary Table 1, http://links.lww.com/MD/G468). However, since lag = 0 refers to the time of exposure to the weather variables at

Table 3

Monthly comparison of variables using analysis of variance.

	Month											
	1	2	3	4	5	6	7	8	9	10	11	12
ER visits	1.97[a]	1.99[a]	2.13[b]	2.54[c]	2.60[c]	2.58[c]	2.37[b]	2.27[b]	2.31[b]	2.35[b]	2.23[b]	2.20[b]
						$F=2.20$, $P=.01$						
Temperature (°C)	1.40[a]	0.74[b]	7.59[c]	14.14[d]	19.81[f]	23.47[h]	26.95[i]	27.54[i]	22.09[g]	15.38[e]	7.53[c]	1.07[b]
						$F=1203.09$, $P < .001$						
Rainfall duration (h)	1.97[a]	2.10[a]	1.86[a]	2.31[b]	1.74[a]	1.39[a]	3.41[c]	2.59[b]	2.36[b]	1.89[a]	1.54[a]	2.16[a]
						$F=2.01$, $P=.02$						
Daily rainfall (mm)	0.29[a]	1.22[b]	1.00[a]	3.23[b]	1.68[b]	1.69[b]	13.22[d]	5.02[c]	4.30[c]	2.45[b]	1.59[b]	0.89[a]
						$F=8.91$, $P < .001$						
Relative humidity (%)	56.79[b]	52.07[a]	51.54[a]	51.51[a]	51.62[a]	58.11[b]	71.36[d]	66.14[c]	67.09[c]	65.21[c]	61.00[b]	59.60[b]
						$F=38.33$, $P < .001$						
Wind speed (m/s)	1.39[b]	1.49[c]	1.57[d]	1.76[f]	1.75[f]	1.67[e]	1.63[e]	1.68[e]	1.52[c]	1.41[b]	1.18[a]	1.30[a]
						$F=14.70$, $P < .001$						
Total sunlight hours	6.27[b]	7.29[c]	7.33[c]	7.74[d]	9.19[e]	8.17[d]	6.19[b]	7.18[c]	6.31[b]	6.38[b]	6.42[b]	5.71[a]
						$F=9.02$, $P < .001$						

Duncan's post hoc analysis: ER visits – a<c, Temperature – a<b<c<d<e<f<g<h<i, Rainfall duration – a<c, Daily rainfall – a<c<d, Relative humidity – a<b<c<d, Wind speed – a<b<c<d<e, Total sunlight hours – a, b<c, d<e.
ER = emergency room.

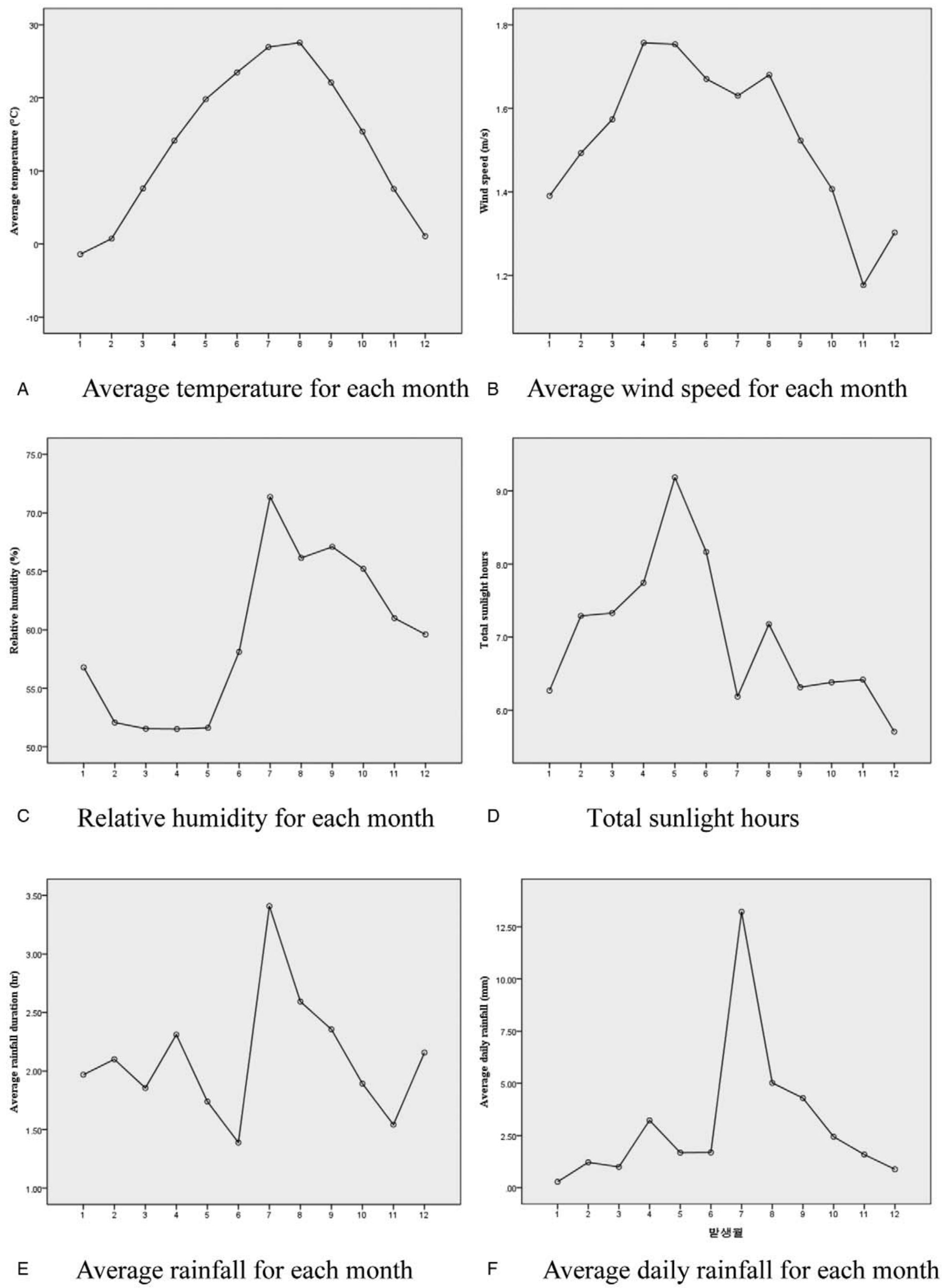

Figure 2. Weather parameters. (A) Average temperature for each month; (B) average wind speed for each month; (C) relative humidity for each month; (D) total sunlight hours; (E) average rainfall for each month; (F) average daily rainfall for each month.

the time of injury, it can be seen that high temperature was associated with a higher relative risk than low temperature.

For the DLNM analysis of average wind speed, the lag-response was confirmed by setting the minimum value (0.5 m/s), maximum value (4.5 m/s), and specific value (2.5 m/s) (Reference Criteria = Median [1.5 m/s]). In the case of high speed (>Ref. 1.5 m/s), compared to low speed (<Ref. 1.5 m/s), the relative risk of trauma patient prevalence significantly decreased (Fig. 4, Supplementary Table 2, http://links.lww.com/MD/G469). In the absence of lag response, it was confirmed that the risk of

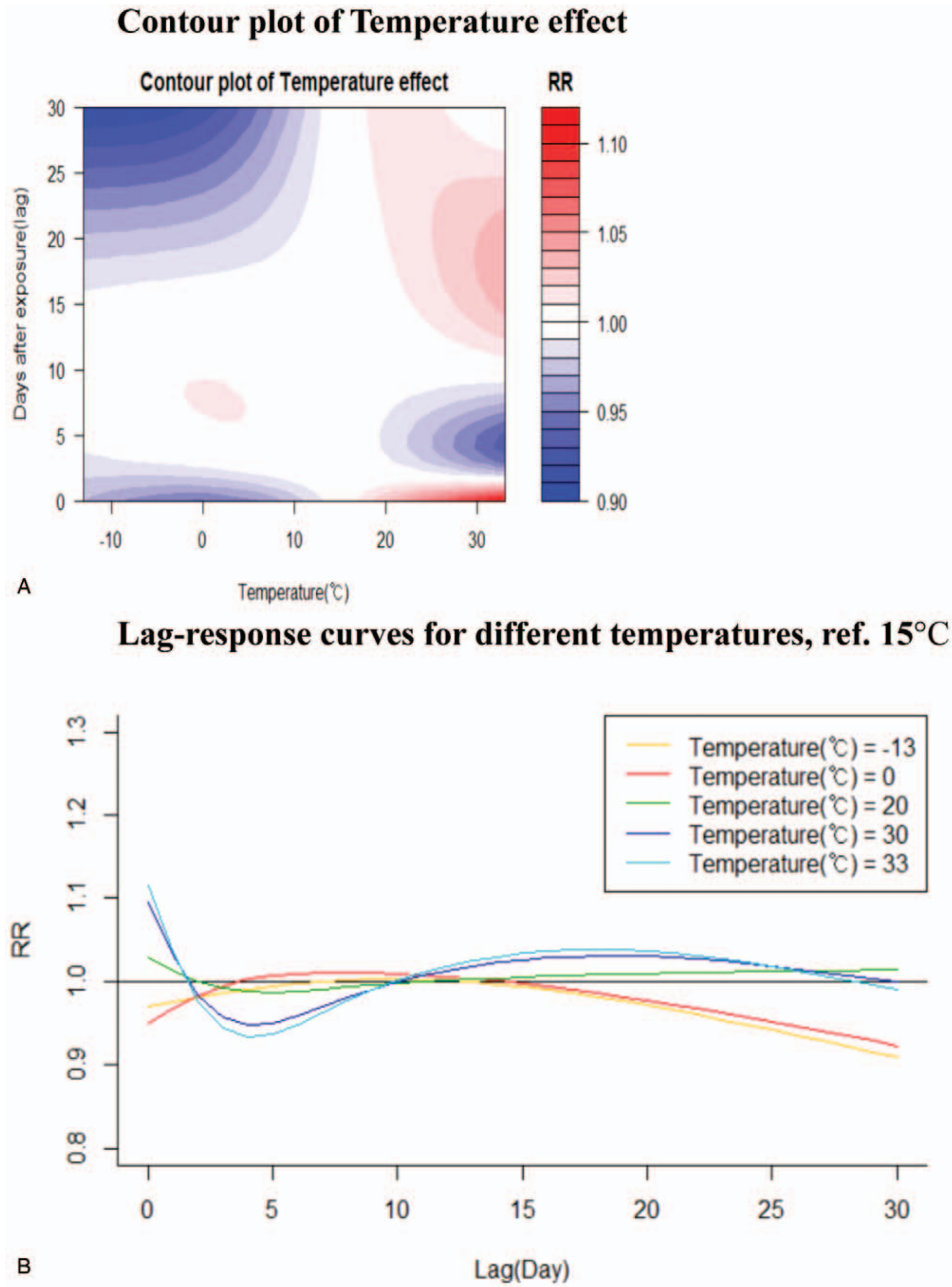

Figure 3. Temperature effect. (A) Contour plot of temperature effect; (B) lag-response curves for different temperatures, Ref. 15°C.

trauma patient prevalence was highest at high speed. In the case of low speed, the risk of trauma patient prevalence according to the lag-response remained higher than that in the case of high speed, but it did not have a significant effect because the slope of the graph curve was small (Fig. 4B).

Analysis of total sunlight hours was performed using DLnM, and the lag-response was confirmed by setting the minimum value (0 hours) and the maximum value (13 hours) (reference criterion = median of 8 hours). The results are shown in Figure 5 and Supplementary Table 3, http://links.lww.com/MD/G470. When the total amount of sunlight was long (>Ref. 8 hours), the risk of trauma was relatively higher than the median value (lag = 0). This result was also observed at the minimum value (0 hours), and the relative risk gradually decreased over time for both short and long total sunlight hours.

The average daily rainfall was analyzed using DLnM (Fig. 6, Supplementary Table 4, http://links.lww.com/MD/G471 and the lag-response was confirmed by setting a specific range (50, 150, 250 mm, reference criteria = median of 0 mm). In the absence of the delay effect (lag = 0), it was confirmed that the relative risk of trauma increased as the amount of precipitation increased. As can be seen from Supplementary Table 4, http://links.lww.com/MD/

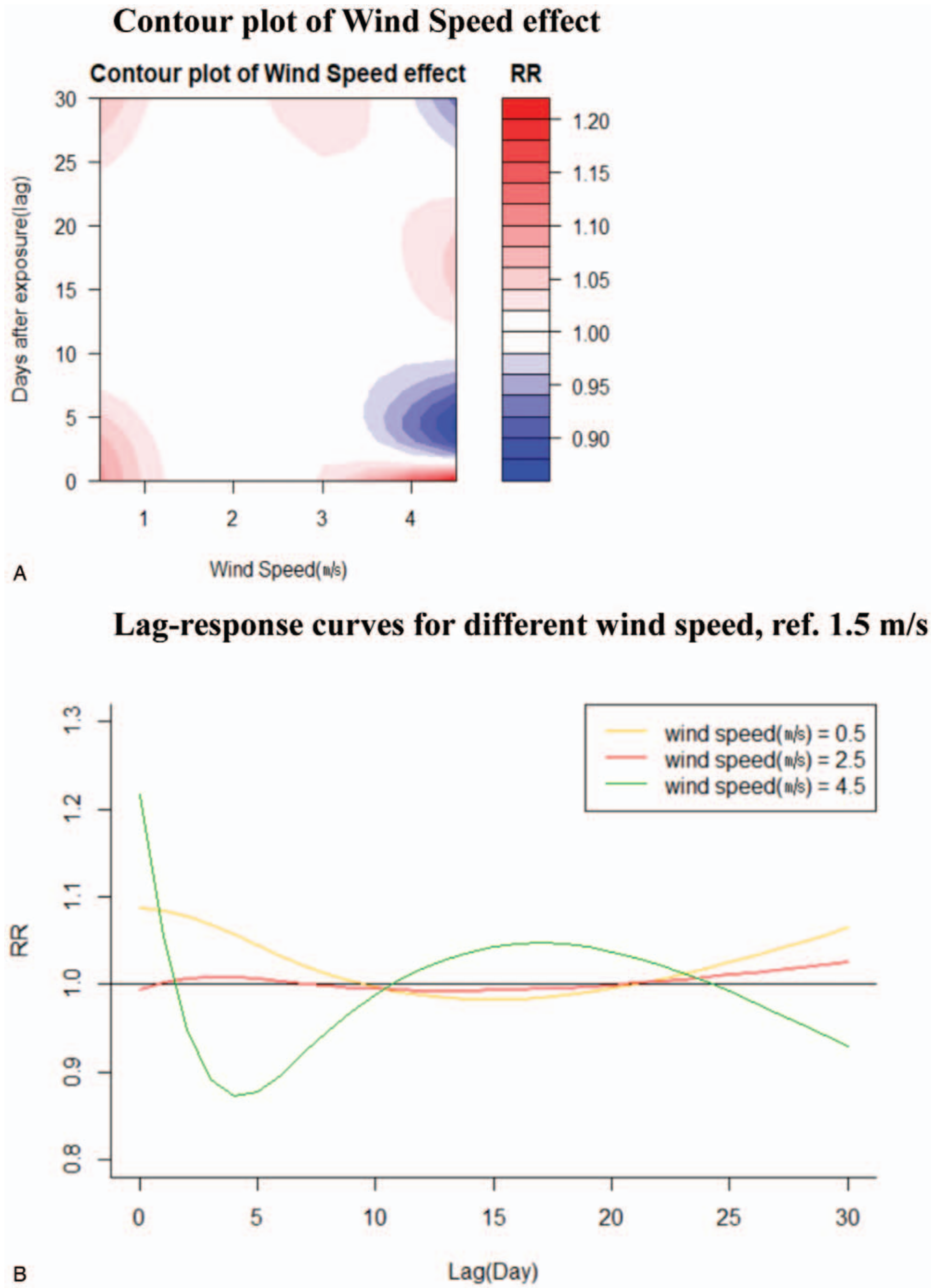

Figure 4. Wind speed effect. (A) Contour plot of wind speed effect; (B) lag-response curves for different wind speed, Ref. 1.5 m/s.

G471 and Figure 6B, the relative risk decreased over time for all precipitation values. When the amount of rainfall was 250 mm or more, the relative risk decreased sharply over time, but there was an effect on the risk by 1 to 2 days (lag 1–2).

Figure 7 and Supplementary Table 5, http://links.lww.com/MD/G472 show the results of the analysis of average relative humidity using DLnM, and the lag-response was confirmed by setting specific values (30% and 80%, reference criterion = median of 59.4%). When there was no delay effect with lag = 0, the relative risk was high at an average relative humidity of 40% to 60%. However, with the passage of time (increasing lag), the relative risk increased at the point where the relative humidity was 80% or more, which means that the delay effect has an impact on the risk of trauma.

In order to confirm the cumulative lag-response of weather variables for 1 month (lag = 30), the two-dimensional DLnM was reduced to a one-dimensional model with the set parameters (Fig. 8). In the case of average temperature, the relative risk of the prevalence of trauma was high when the temperature was high compared to when the temperature was low based on the

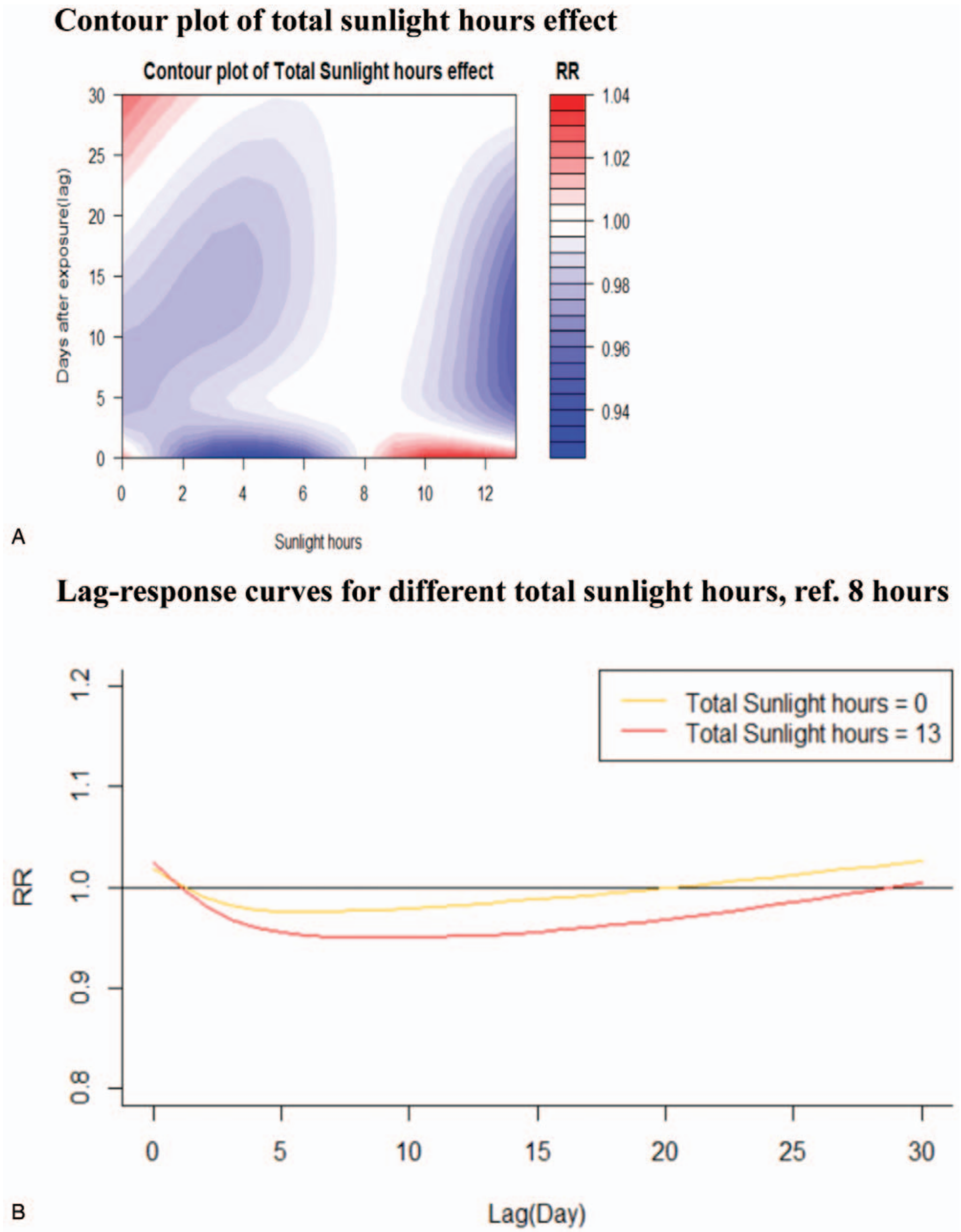

Figure 5. Total sunlight hours effect. (A) Contour plot of total sunlight hours effect; (B) lag-response curves for different total sunlight hours, Ref. 8 h.

reference value (8°C). Therefore, the higher the temperature, the higher the risk of trauma patients visiting the ER. As regards average wind speed, it was confirmed that a wind speed less than the reference value (1.5 m/s) led to a high degree of risk of trauma patients. In other words, the lower the average wind speed, the greater the impact on the risk of trauma patients. In the case of the total amount of sunlight, the risk of morbidity in trauma patients was not affected in the case of less or more than the reference value (8 hours). As regards average daily rainfall, it was confirmed that the relative risk of the trauma patient prevalence was greatest when the daily precipitation was about 100 mm based on the reference value (0 mm). However, at rainfall of 150 mm or more, the risk was lowered, and it does not affect the risk of trauma. In the case of relative humidity, when the relative humidity was 80% or more based on the reference value (59.4), the risk appeared to be the greatest, whereas the risk was small when relative humidity was less than 30%.

Multiple linear regression analysis was conducted to verify the influence of weather variables that were significant in the linear regression analysis on the incidence of trauma (Table 4). The regression model was significant ($F=6.605$, $P<.001$), and the variance inflation factor was less than 10 (no issues with multicollinearity). Verification of significance of the regression coefficient showed that the incidence of trauma increased with the average daily temperature ($\beta=0.069$, $P=.009$) and the average daily total sunlight hours ($\beta=0.073$, $P=.005$). Comparison of

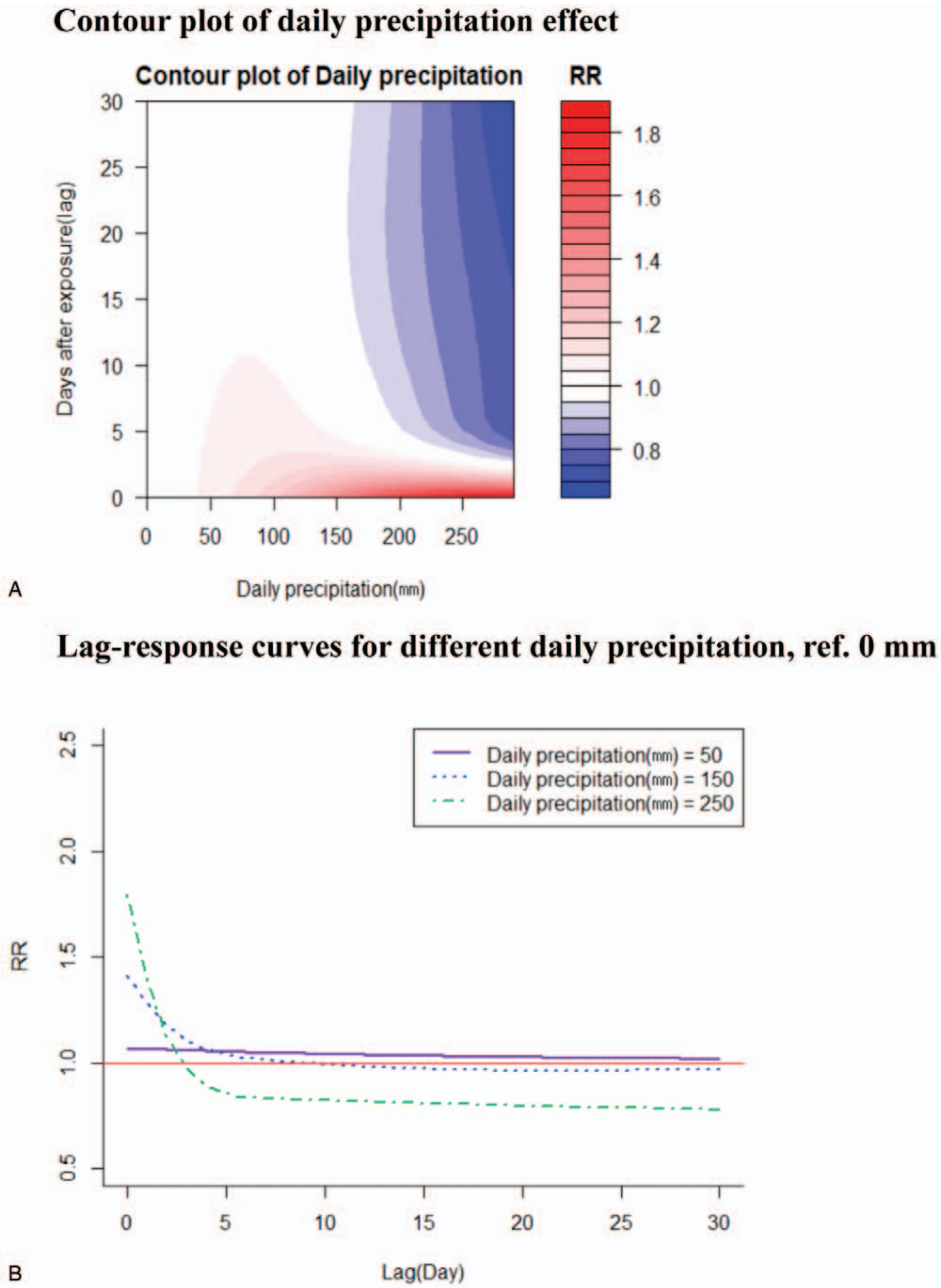

Figure 6. Daily precipitation effect. (A) Contour plot of daily precipitation effect; (B) lag-response curves for different daily precipitation, Ref. 0 mm.

the size of the standardization coefficient showed that the average daily sunlight hours (β=0.073) had a greater effect on the incidence of trauma than the average daily temperature (β= 0.069).

4. Discussion

To develop a community-based emergency trauma system, we studied the relationship between meteorological factors and the incidence of trauma in our regional trauma center from January 2016 to December 2019.

The majority of the 3352 participants were men (n=2132, 63.6%). This was the case in previous studies as well: Ho et al[8] reported that 76.30% of the participants were male and Lin et al[10] reported 55.47% males in their study population. However, a study conducted in 2020 showed that 52.5% of the patients admitted for trauma were women, but the average age of women was 70.5 years and that of men was 45.1 years.[11] According to the World Health Organization, men suffer more from trauma-related deaths than women worldwide, but the sex and age distributions of the occurrence of trauma differ by region.[12]

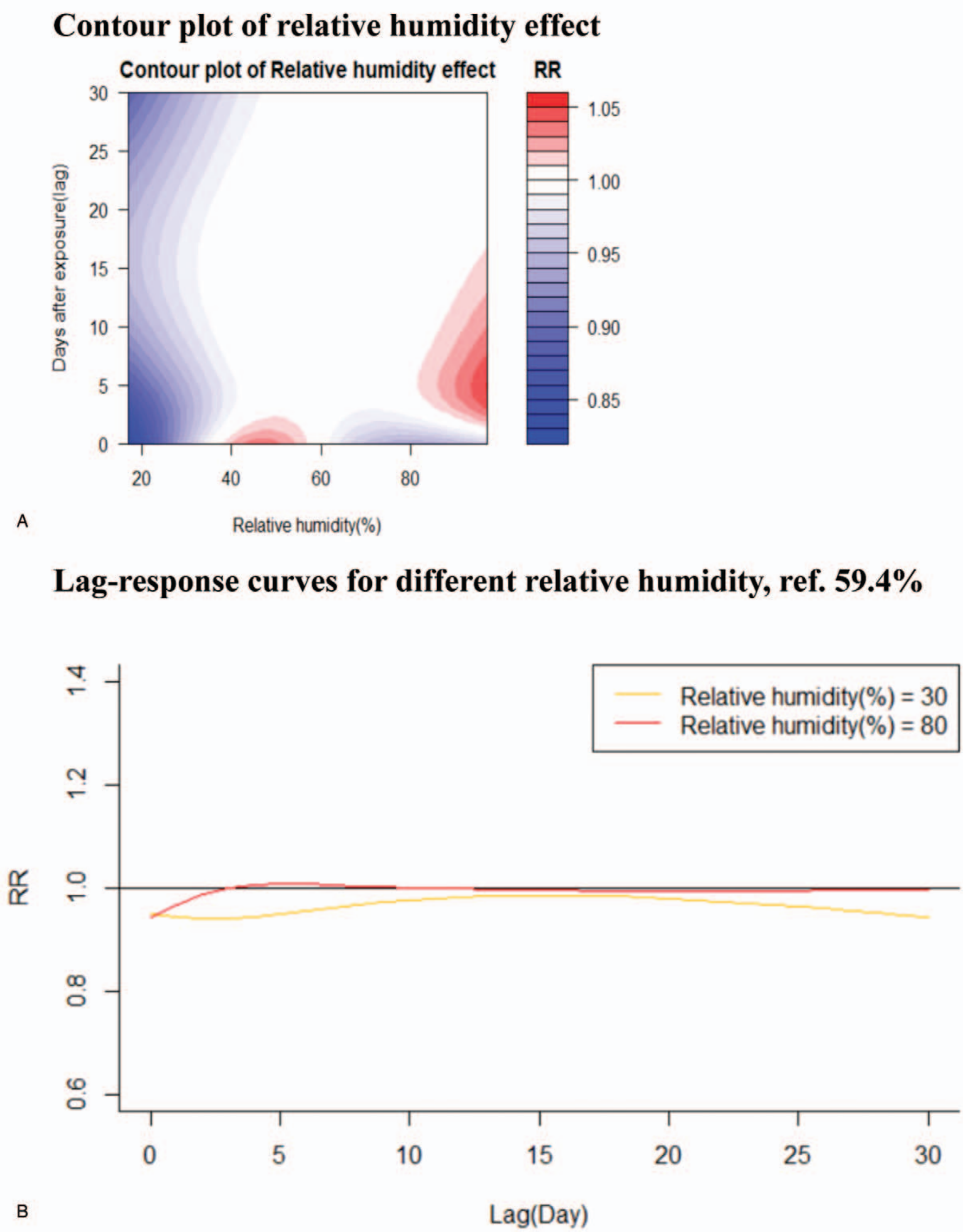

Figure 7. Relative humidity effect. (A) Contour plot of relative humidity effect; (B) lag-response curves for different relative humidity, Ref. 59.4%.

Several studies have revealed that the incidence of trauma is affected by the season and month and that it tends to increase during spring and summer.[7–9,11] In a study conducted by Bhattacharyya and Millham, of the 9408 trauma patients admitted to a hospital in 5 years, the average daily number of trauma admissions increased by 28% in July and 17% in August, at a significant level.[9] A study conducted by William et al at a level-1 trauma center also showed an increase in the number of trauma patients in July and August. Both studies indicated that the incidence of trauma increased with temperature in July and

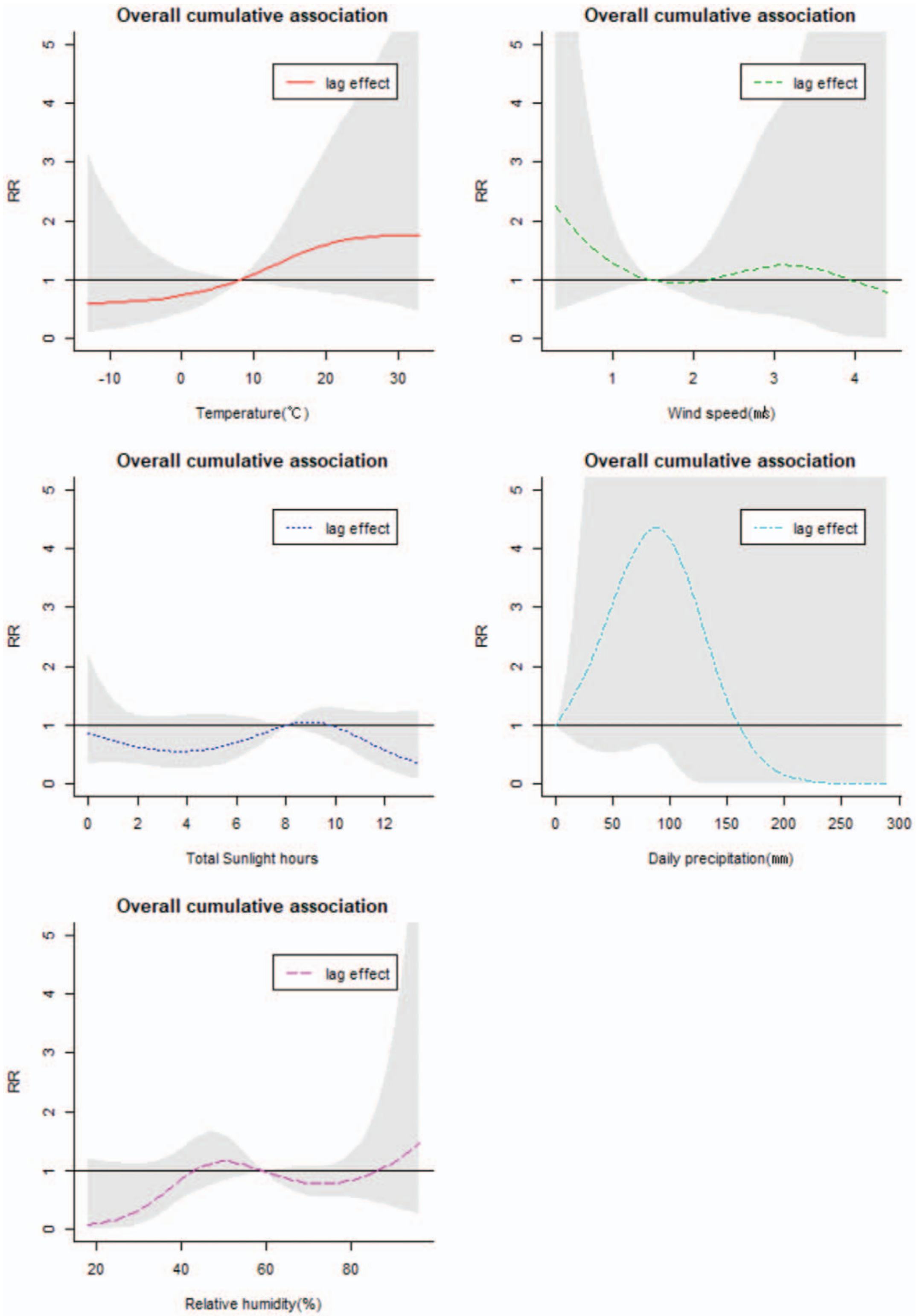

Figure 8. Overall cumulative association.

August and demonstrated a positive correlation between the number of trauma patients and the maximum temperature. In this study, it was also confirmed that the risk of trauma patients increased due to temperature increase on analyzing the average temperature in the DLnM. However, we determined that the highest number of trauma incidents occurred in April, May, and June, when the average temperatures were lower than those in July and August (highest average temperatures). Røislien et al

Table 4

Multiple linear regression analysis to predict the number of trauma patients admitted to the emergency room.

Variable	B	SE	β	t	P	VIF
Temperature (°C)**	0.010	0.004	0.069	2.605	.009	1.020
Total sunlight hours**	0.030	0.011	0.073	2.802	.005	1.008
$F=6.605$ ($P<.001$), $R^2=0.013$, $_{adj}R^2=0.011$, $D–W=1.932$						

VIF = variance inflation factor.
* $P<.05$
** $P<.01$.

reported that the incidence of trauma was the highest in May, when the temperature was lower than that in the summer,[3] similar to our study findings. Weather factors other than temperature seem to have a complex effect on the incidence of trauma, and this study showed that the weather variables also have a complex correlation with each other.

In a study conducted in 2015, a correlation analysis demonstrated that the incidence of trauma decreased with increasing duration of rainfall, amount of snowfall, or duration of cloudy weather.[8] However, the relationship between rainfall and the incidence of trauma remains controversial. Although several studies have demonstrated a decrease in the incidence of trauma with increased rainfall,[8,9,13] some have reported an increase.[14,15] In this study, the incidence of trauma increased as the daily average rainfall increased, but the DLnM analysis showed that the risk of trauma patients decreased when it reached a certain level (150 mm).

The relationship between relative humidity and the incidence of trauma has not yet been clearly shown. Several studies have reported decreased trauma incidents with a rise in relative humidity, but this was not significant.[9,14] In our study, the incidence of trauma was high when the relative humidity was 40% to 60%. The DLnM analysis showed that the frequency of trauma patients increased when humidity was 80% or more for a prolonged period.

A 2018 Korean study[16] reported that the incidence of trauma tends to decrease as wind speed increases, although the results were not statistically significant. Our study also proved that the risk of having trauma patients increases as the average wind speed decreases through DLnM analysis. However, when the delay effect was not considered, the incidence of trauma was high at high wind speed (4.5 m/s). Several other studies have not been able to prove that wind speed affects the incidence of trauma.[8,14,17]

This study showed that the risk of trauma was relatively higher than the median value (lag = 0) when the amount of daily total sunlight hours was long (>Ref. 8 hours). However, no significant results were observed in the lag-response. Røislien et al[3] reported that number of hours of sunlight had a stronger correlation than average temperature. In 2015, Lin et al reported that among several weather variables, the increase in duration of sunlight had the greatest effect on the incidence of trauma.[10] Our study also proved that daily sunlight had a greater effect on the incidence of trauma than temperature in the multiple linear regression analysis, as in previous studies.

This study showed similar results to several studies conducted in the past, and sometimes contradictory results. As such, the difference in results between several studies can be explained by several limitations in this study. The first limitation is that this study aimed to determine the correlation between weather variables and the incidence of trauma in a regional setting. Due to regional limitations, approximately 30% of the patients were excluded from the study. In addition, it is difficult to apply our research results to regions with different weather characteristics. Second, as this study was designed retrospectively, it has limitations. Third, the study was conducted at a regional trauma center with patients from a single center; thus, the sample size was small and not all traumas occurring in the region were included in the study. These limitations can be overcome if the research period is further extended in the future and if the research is conducted jointly with various regional trauma centers and emergency medical centers.

5. Conclusion

In conclusion, an increase in temperature, an increase in the amount of sunlight, an increase in rainfall, high wind speed, and relative humidity of 40% to 50% are associated with a relatively high prevalence of trauma patients. However, each weather element changes in many ways according to the continuity of time, warranting further research to draw conclusive results.

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Author contributions

S.H.K. contributed to the acquisition of data, analysis and interpretation of the data, and drafting of the manuscript; Y.H.S. contributed to study conception and design, acquisition of data, and critical revision of the manuscript; J.S.K. contributed to the critical revision of the manuscript. All authors reviewed and approved the final submitted manuscript.

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Methodology: Se Heon Kim.
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Writing – original draft: Se Heon Kim.
Writing – review & editing: Young Hoon Sul, Joong Suck Kim.

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