

Correlations of Weather and Time Variables with Visits of Trauma Patients at a Regional Trauma Center in Korea

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Purpose: Trauma incidence and hospitalizations of trauma patients are generally believed to be affected by season and weather. The objective of this study was to explore possible associations of the hospitalization rate of trauma patients with weather and time variables at a single regional trauma center in South Korea.

Methods: Trauma hospitalization data were obtained from a regional trauma center in South Korea from January 1, 2017 to December 31, 2019. In total, from 6,788 patients with trauma, data of 3,667 patients were analyzed, excluding those from outside the city where the trauma center was located. Hourly weather service data were obtained from the Korea Meteorological Administration.

Results: The hospitalization rate showed positive correlations with temperature ($r=0.635$) and wind speed ($r=0.501$), but a negative correlation with humidity ($r=-0.620$). It showed no significant correlation ($r=0.036$) with precipitation. The hospitalization rate also showed significant correlations with time of day ($p=0.033$) and month ($p=0.22$).

Conclusions: Weather and time affected the number of hospitalizations at a trauma center. The findings of this study could be used to determine care delivery, staffing, and resource allocation plans at trauma centers and emergency departments.

Keywords: Weather; Time; Temperature; Wounds and injuries; Patient admission

INTRODUCTION

There is a widespread belief among medical professionals at trauma centers that fewer trauma patients are hospitalized on rainy days. In addition, the volume of trauma patients varies depending on time and other circumstances. Higher temperatures, precipitation, evenings, and weekends are associated with an increased volume of trauma patients presenting to the emergency department. The effects of time variables (such as season, month, day, and hour) and weather variables on the volume of trauma patients have been analyzed in several previous papers. Bhattacharyya and Millham [1] argued for a strong correlation between trauma patient volume and daily high temperatures. Conversely, increased precipitation decreased trauma hospitalizations by 10%. Atherton et al. [2] reported that the admission of trauma cases was related to weather and time factors, especially for pediatric trauma cases. There is substantial annual variation from month to month, and even daily and weekly. Abbasi et al. [3] analyzed patterns of trauma patients at a major trauma center in Shiraz, in southern Iran, and found that most trauma injuries were reported during in summer and hot weather. Thus, we hypothesized that the volume of incoming trauma patients at a regional trauma center could be predicted by weather and time variables. This information can be used to facilitate the treatment and management of trauma patients. This study aimed to help treat trauma patients and manage trauma centers by exploring the association of patients' rate of hospitalization with seasonal

Table 1. Demographic and injury-related characteristics of the trauma patients

	Total (n=3,667)
Age	54.42±21.09
Sex	
Male	2,419 (66.0)
Female	1,248 (34.0)
Mechanism of injury	
Fall	1,695 (46.2)
High energy fall	993 (25.5)
Trivial fall	762 (20.7)
Traffic accident	1,287 (35.1)
Pedestrian	545 (14.9)
Motorcycle	387 (10.6)
Car	271 (7.4)
Bicycle	84 (2.3)
Others	685 (18.7)
Primary department	
Neurosurgery	1,106 (30.2)
Trauma surgery	951 (25.9)
Orthopedic surgery	950 (25.9)
Emergency medicine	445 (12.1)
Plastic surgery	66 (1.8)
Others	149 (4.1)
ISS	
>16	2,255 (61.5)
≤16	1,412 (38.5)

Values are presented as mean±standard deviation or number (%).
ISS: injury severity score.

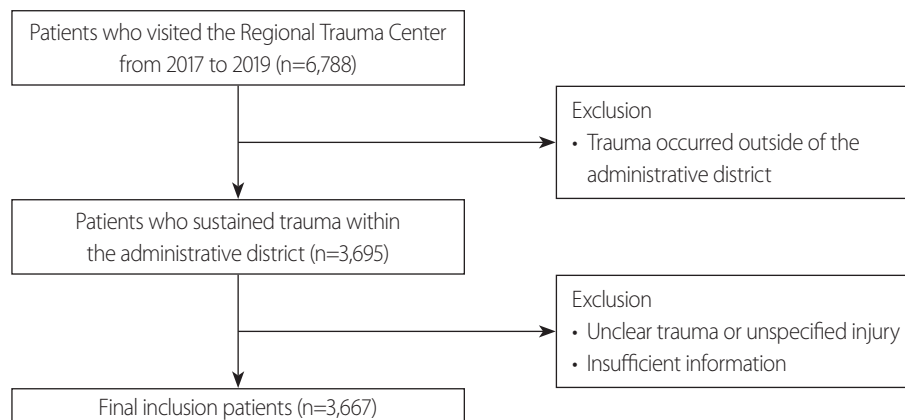


Fig. 1. Study design and sampling.

variables and temperature.

METHODS

Records from 6,788 patients who were treated at a regional trauma center of Pusan National University Hospital from 2017 to 2019 were reviewed. Data from

3,667 patients were collected after excluding those who sustained injuries outside the administrative district of the city where the trauma center was located, patients with unclear trauma history or an unspecified injury, and patients with insufficient information (Fig. 1). Data included age, sex, accident time, accident mechanism, anatomic location of injury, and severity index of trauma. Data for weather variables were obtained from

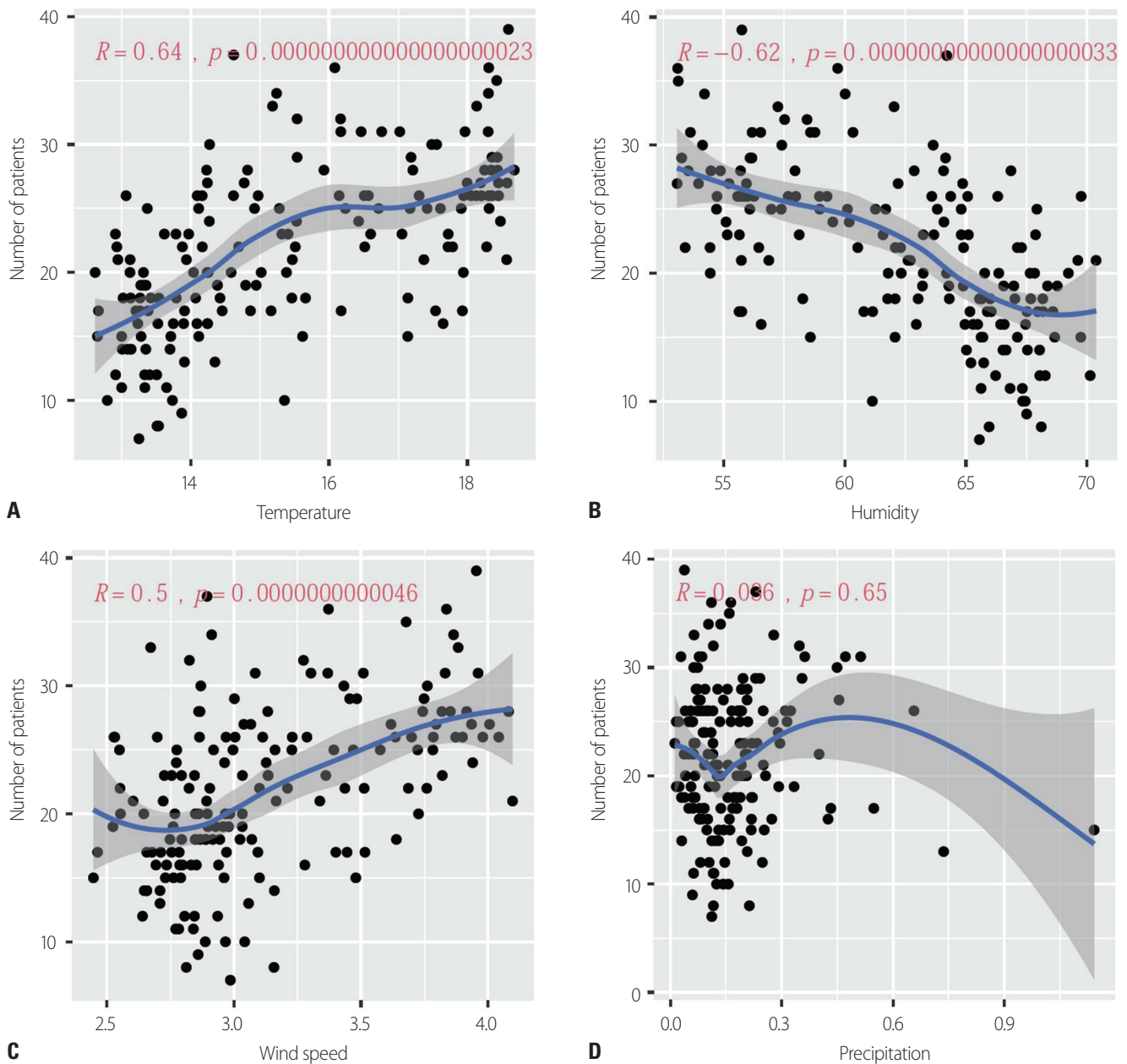


Fig. 2. (A-D) Scatter plot of the number of trauma patients according to weather variables.

Table 2. Correlations between individual weather variables and trauma patients

Weather variable	Spearman <i>r</i>	<i>p</i> -value	Absolute correlation value
Temperature (average)	0.635	0.000 ^a	0.635
Humidity (average)	-0.620	0.000 ^a	0.620
Freezing days	-0.555	0.000 ^a	0.555
Wind speed (average)	0.501	0.000 ^a	0.501
Precipitation (average)	0.036	0.646	0.036
Snowfall (average)	0.008	0.915	0.008
Heavy rain days	-0.027	0.727	0.027

^a*p*<0.05.**Table 3.** Number of trauma patients according to time variables; hourly data (time of day)

Hour	Value
0-1	130 (3.5)
1-2	109 (3.0)
2	115 (3.1)
3	95 (2.6)
4	106 (2.9)
5	110 (3.0)
6	131 (3.6)
7	115 (3.1)
8	153 (4.2)
9	176 (4.8)
10	187 (5.1)
11	158 (4.3)
12	166 (4.5)
13	199 (5.4)
14	202 (5.5)
15	192 (5.2)
16	191 (5.2)
17	171 (4.7)
18	188 (5.1)
19	153 (4.2)
20	155 (4.2)
21	183 (5.0)
22	148 (4.0)
23	134 (3.7)

Values are presented as number (%).

the Korea Meteorological Administration. The weather station that collects weather variables was located 1.2 km away from the trauma center and weather variables were measured every hour. The weather data contained information such as temperature, precipitation, humidity, snowfall, wind speed, and icy road conditions. Group-by-group comparisons of continuous variables were performed using the independent *t*-test or Wilcoxon rank-sum test. Correlations between weather variables and the number of patients were determined by univariate analysis. Spearman correlation coefficients were calculated to determine the linear relationships between weather variables and patient volume. For the analysis of daily data, we analyzed mean temperature values, which are closely correlated with the highest, lowest, and average temperatures, using raw data established at intervals of 1 hour. In the scatter plot, the *R* value denotes the Spearman rank correlation coefficient, and the trend line was checked for linearity using the loess method (local polynomial regression).

RESULTS

Of 3,667 patients who presented to the trauma center

Table 4. Number of trauma patients according to time variables; monthly data

Month	Value
January	295 (8.0)
February	262 (7.1)
March	317 (8.6)
April	302 (8.2)
May	341 (9.3)
June	279 (7.6)
July	328 (8.9)
August	321 (8.8)
September	312 (8.5)
October	302 (8.2)
November	294 (8.0)
December	314 (8.6)

Values are presented as number (%).

from January 1, 2017 to December 31, 2019, 2,419 (66.0%) were men and 1,248 (34.0%) were women. Their average age was 54.4 years. The most common cause of trauma was falls, in 1,695 cases (46.2%), followed by traffic accidents in 1,287 patients (35.1%) (Table 1). Due to the nature of a regional trauma center, most patients experienced multiple traumas. According to the anatomical site, the most common category was neurosurgical injuries (1,106 cases, 30.2%), followed by thoracic and abdominal injuries (951 cases, 25.9%) and orthopedic injuries (950 cases, 25.9%). Major trauma with an injury severity score of ≥ 16 was observed in 1,412 patients (38.5%). The volume of trauma patients showed a positive correlation with temperature ($r=0.635$) and wind speed ($r=0.501$), but a negative correlation with humidity ($r=-0.620$) (Fig. 2). However, it did not show any statistically significant correlations with other variables such as precipitation, snowfall, or icy road conditions (Table 2).

The correlation between time of day and the number of hospitalizations was significant ($p=0.033$). The number of patients peaked during 1–3 PM (over 5.4%). Patient volume also showed significant ($p=0.22$) correlations with monthly variables, especially in May, July, and August (over 8.8%) (Tables 3, 4). However, it showed no significant correlation with days of the week or seasonal variables (Figs. 3, 4).

DISCUSSION

In this study, we confirmed the correlation between the hospitalization rate of trauma patients and certain weather and time variables. Traumatic events occur more frequently at certain times and months [1,4-10]. The incidence of traumatic events was found to vary significantly with the time of day. It was 2.1-fold higher between 2:00

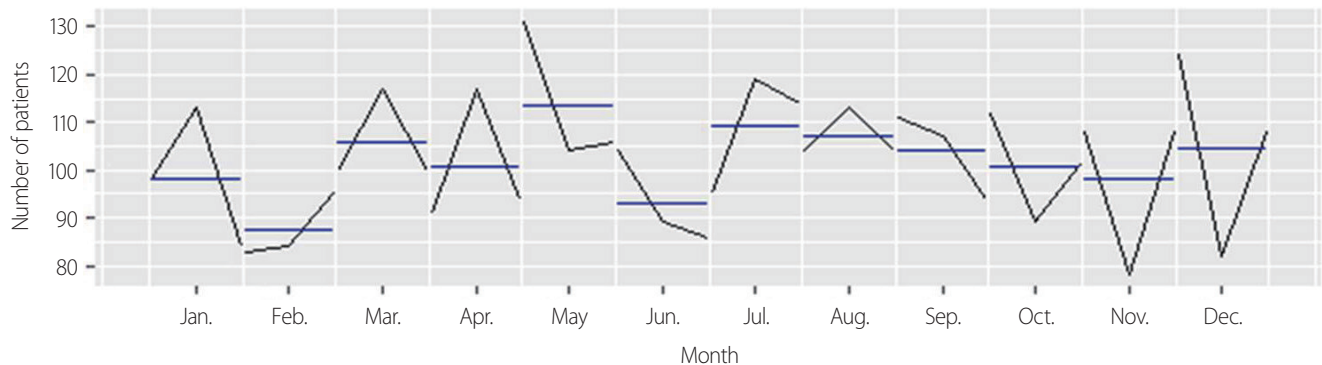


Fig. 3. The monthly time plot of trauma patients. A subseries plot was created using ggplot. Each season is plotted as a separate mini time series. The blue lines represent the mean of the observations within each season.

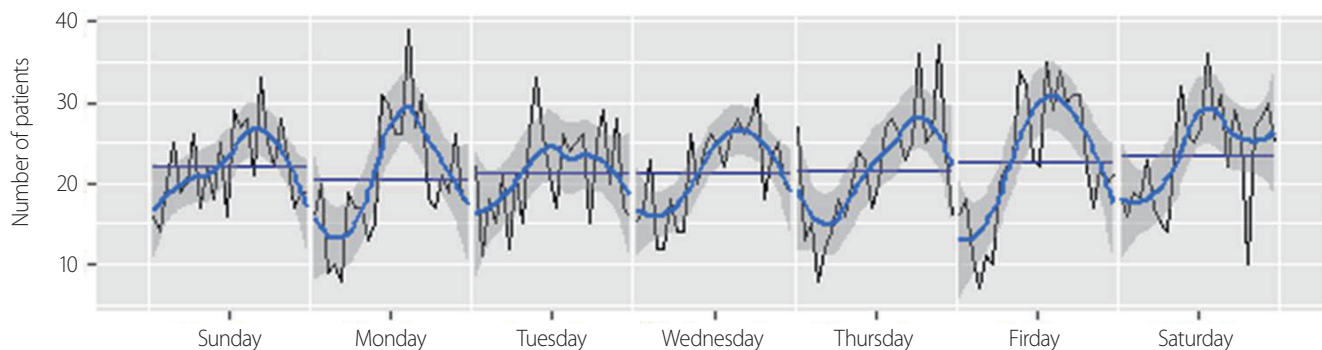


Fig. 4. Time series of weekly trauma patients.

and 3:00 PM than that at 3:00 AM and 4:00 AM. The number of trauma cases was 1.3-fold higher in May than in February. However, February has fewer days than other months. Weather is also an important factor, as higher temperature and wind speed and lower humidity were associated with a higher incidence of trauma. Extreme temperatures and humidity decreased the incidence of trauma.

Bhattacharyya and Millham [1] analyzed weather and trauma data in Boston from September 1992 to August 1998 and found a strong correlation between hospitalizations and maximum daily temperatures among trauma patients. High precipitation (over an inch) was related to a 10% reduction in the number of trauma admissions. Humidity and snowfall did not affect the trauma admission rate. Saturday (24%) and Sunday (8%) were associated with significantly higher numbers of trauma admissions. Significantly higher patient volume was also found in July (28%) and August (17%).

Rising et al. [4] conducted a retrospective study of the relationship between weather and the number of patients presenting to a level 1 trauma center in Louisville, KY from 1996 to 2002 and reported that high temperatures and precipitation were important factors affecting the hospitalization of patients with injuries. That study showed that daily high temperature and precipitation were valid predictors of trauma admission volume, with a 5.25% increase in hourly incidents for each 10°F difference in temperature and a 60% to 78% increase in the incidence rate for each inch of precipitation in the previous 3 hours.

Ho et al. [11] analyzed the relationship between weather and trauma patient hospitalization at a level 1 trauma center in Queens, NY from January 2000 to December 2009 and found that temperature was significantly related to trauma hospitalization; in particular, a strong association was found with penetrating trauma, reflecting a statistically significant correlation between climate and crime. Livingston et al. [9] analyzed the relationship between pediatric orthopedic trauma and weather variables from July 2009 to March 2012. They reported that the number of trauma hospitalizations increased by 1% for each degree of temperature increase and decreased by 21% per inch of precipitation. Mogaka et al. [12] inves-

tigated the relationship between precipitation and traffic accidents and found that rainy weather (odds ratio [OR] 2.9; 95% CI 1.3–6.5) and night-time crashes (OR 2.0; 95% CI, 1.1–3.9) were independent factors associated with serious injuries in traffic accidents.

It was challenging to study the correlation between snowfall and trauma hospitalization. Due to the geographic location of a regional trauma center of Pusan National University Hospital, we cannot record meaningful snowfall throughout the year. Lee et al. [6] analyzed the correlation between traffic accidents and weather in Seoul between May 2007 and December 2011 based on Korea Road Traffic Authority information. The risk of road traffic injury during snowfall increased when the temperature was below 0°C. Road traffic injuries increased by 6.6% at temperatures above 0°C with snowfall, and by 15% at temperatures below 0°C. Due to heavy rain, moderate temperatures are related to increased injuries. The frequency of road traffic accidents increased by 12% at temperatures of 0–20°C, whereas they increased by 8.5% and 6.8% at temperatures below 0°C and above 20°C, respectively.

Our investigation showed that wind speed was positively correlated with trauma. In 1990, Cugnoli and Whitworth [13] reported that trauma increased when wind speed increased, especially when the speed was 60 knots or higher. High temperature, low humidity, and high wind speed are generally regarded as components of pleasant weather. In such weather conditions, people generally increase their activities. Ranandeh Kalankesh et al. [14] analyzed relationships of trauma-related death with temperature and humidity. Their study analyzed the role of leisure activities such as traveling in correlation with high temperatures and warm seasons.

Time variables (seasonal, monthly, daily, and hourly data) can also affect patient volume at hospitals. Holleman et al. [5] analyzed the role of calendar and weather variables from 1991 to 1994 in the volume of patients at the University of Kentucky Medical Center. Adding weather variables changed the effect of season. Compared to winter days, summer days had 6.1 fewer patients on average, while December days had 3.0 fewer patients. Calendar variables and weather variables forecasted clinic volume, explaining 84% of daily variance and 44% of

weekday variance.

Rotstein et al. [15] conducted a retrospective study of patients presenting to the Chaim Sheba Medical Center emergency room in Tel Hashomer, Israel from 1992 to 1994. That study showed that the fewest visits occurred between December and March, while the highest number of visits occurred from April to September. The authors found the highest number of patients on Sundays (a regular workday in Israel), while the lowest number of patients was found on Saturdays. Temperature, rainfall, and humidity were significantly correlated with emergency visits. Koren et al. [16] studied correlations between proximal hip fractures and time variables in 2,050 patients aged 65 years and older and found that the elderly experienced a higher incidence of proximal hip fractures during winter and a lower incidence on weekends. Lankarani et al. [17] studied traffic accidents and time variables and reported that traffic accidents were more frequent during sunset and sunrise than during the day or night.

Our study found that trauma incidence significantly increased at 1–3 PM and in May, July, and August. It should also be noted that July and August are common vacation and travel months in Korea, and Busan is a popular travel destination. This supports the hypothesis that the weather variables mentioned above, especially pleasant weather, may have affected people's activity, rather than a certain season of the year independently increasing trauma incidence.

As of 2015, 7,307 patients died from trauma in Korea, of whom 6,708 died after being admitted to the hospital, while 599 died in the emergency department [18]. A proper analysis of these patients is important for improving patient survival since the personnel and resources available at the emergency department of trauma centers are generally limited. Additionally, the death rate of mass casualty incidents is 6.78 per 100,000 persons in Korea. Utilizing the limited hospital resources available can help reduce preventable mortality [19].

Unlike previous studies, we analyzed the hospitalization rate of trauma patients according to both time and weather variables. Accurate weather information and a proper analytical method are needed to utilize data in the management of the trauma care system. Flexible and systemic resource allocation based on patient trend data

analyzed according to weather and time variables should be considered. Establishing a system such as preparing backup medical personnel or compensating existing staff for an increased workload can ultimately help treat trauma patients. Furthermore, this study may furnish useful information for trauma prevention initiatives, such as a public awareness campaign.

One limitation of our study is that the data only included a single trauma center. In 2019, only 48% of trauma patients in Busan were admitted to the regional trauma center. Thus, the cases analyzed in this study do not fully reflect the entire scope of trauma incidence in the region. Due to the nature of a dedicated trauma center, our institution has a bias towards multiple or severe trauma cases, rather than simple trauma or minor trauma cases.

Furthermore, in Busan, which encompasses an area of 769.82 km², there is only one weather station and dataset available for public use. More data from multiple independent sources of measurement and a more robust statistical process are needed to produce more accurate representations of weather conditions.

CONCLUSION

High temperatures, high winds, low humidity, and certain times of day are important and valid predictors of trauma hospitalization. The results of this study can be used to determine the placement and resource utilization of trauma centers. By appropriately deploying personnel and resources, the survival rate of trauma patients can be improved. However, further studies are needed to assess whether these weather and time variables are specific to a particular climate or can be generalized and applied to a variety of geographical locations.

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