

Heat Stroke and the Thermal Environment

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Abstract

In recent years, heat stroke has become a major concern due to a sharp rise in the number of patients and deaths. The aim of this study was to investigate the relationship between the occurrence of heat stroke and meteorological conditions, using data from patients transported by ambulance in Tokyo and ordinance-designated cities.

There was a trend for patients from heat stroke in Tokyo and ordinance-designated cities to increase, with the number of patients reaching a record high in 2010. The incidences of heat stroke in 2010 ranged from 536.9 persons (Saitama City) to 105.4 persons (Sapporo City) per 1,000,000 persons. As to gender, there were 2.21 times as many male as female patients. Concerning the age class, elderly people was highest, followed by junior and senior high school students. The major cause and place of heat stroke occurrence was at home for the elderly, during exercise for junior and senior high school students, and at work for adults.

When the relationship between the occurrence of heat stroke and meteorological conditions was examined, the annual number of patients in cities was found to be related to some meteorological indices; the mean daily maximum temperature and the number of extremely hot days ($\geq 35^{\circ}\text{C}$) during the summer. The daily number of patients from heat stroke correlated strongly with the daily maximum temperature. In addition to the daily maximum temperature, relationships with acclimatization (early summer > middle or late summer) and humidity (high correlation with wet-bulb globe temperature) were also demonstrated.

Key words Heat stroke, Ambulance-transported patients, Daily maximum temperature, Wet-bulb globe temperature (WBGT)

Introduction

In Japan, it was very hot in the summer 2010. About 56,000 people were transported by ambulance because of heat stroke (according to the Fire and Disaster Management Agency: Statistics of Heat Stroke 2010), and 1,718 people died (according to the Ministry of Health, Labour and Welfare of Japan: Vital Statistics 2010). In this paper heat stroke is used as a physical disorder caused by hot environment, which is a generic concept comprising various physical abnormalities originating from impairment of the physical adjustment, such as thermoregulation, in a hot environment. In addition to heat,

the risk of developing heat stroke increases according to physiological conditions (elderly, infancy, people with various diseases), exertion (work, exercise), and individual physical conditions. As factors other than heat have already been described in other literature, this paper focuses on the thermal environment.

Data

Information on patients from heat stroke

In addition to data of patients who visited hospital and information of deaths (mortality data from vital statistics, postmortem and autopsy data from the Medical Examiner's Office), ambulance

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transport records are available as information on patients from heat stroke. Whereas use of the former two data types are restricted by various limitations (difficult hurdle to data use procedures), ambulance transport records are computerized across the country, and applied to the heat stroke patient information system utilizing those data on a nationwide scale. At present, the information system of heat stroke patients are served by the National Institute for Environmental Studies (NIES) and by the Fire Disaster Management Agency of the Ministry of Internal Affairs and Communications of Japan. This article used information on ambulance-transported heat stroke patients provided to NIES by the Tokyo metropolitan government and 17 ordinance-designated cities across the country.

Meteorological information

Data from meteorological observatories and weather stations in Tokyo and ordinance-designated cities were used. In addition, we used wet-bulb globe temperature (WBGT) observed in 6 areas (Tokyo, Nagoya, Niigata, Osaka, Hiroshima, Fukuoka) by the Ministry of the Environment of Japan.

WBGT is obtained by the following equation using wet-bulb temperature (T_w) and globe temperature (T_g) in addition to dry-bulb temperature (ambient temperature, T_a):

$$WBGT = 0.7 \times T_w + 0.2 \times T_g + 0.1 \times T_a$$

Current Situation of Heat Stroke Occurrence Based on Information System on Heat Stroke Patients of NIES

Figure 1 shows annual trend in the number of patients from heat stroke in Tokyo and 5 ordinance-designated cities. The number of patients tended to increase. The numbers of patients in all cities were far greater in 2010 than in 2007, the previous peak year, and showed a record high in all cities. The ratios of the number of patients in 2010 to that in 2007 tended to be high in eastern and northern areas, whereas ratios tended to be slightly low in western and southern areas.

The incidence of heat stroke (number of patients per 1,000,000 persons) in 2010 was highest, 536.9 patients, in Saitama City, followed by 520.2 patients in Kyoto City. In contrast, low incidence rates were found in Sapporo City (105.4 patients), Nagoya City (234.8 patients), Shizuoka City (254.0 patients), and Yokohama City (258.4 patients).

Figure 2 shows the incidence of heat stroke by gender and age groups. In each age group, males outnumbered females; the number of male patients was 2.21-fold higher than that of female patients when all age groups were combined. As to age, elderly patients were most frequent in both males and females, followed by elementary to junior or senior high school students (ages 7–18). Nearly half of the heat stroke patients in elderly people had suffered the onset at home.

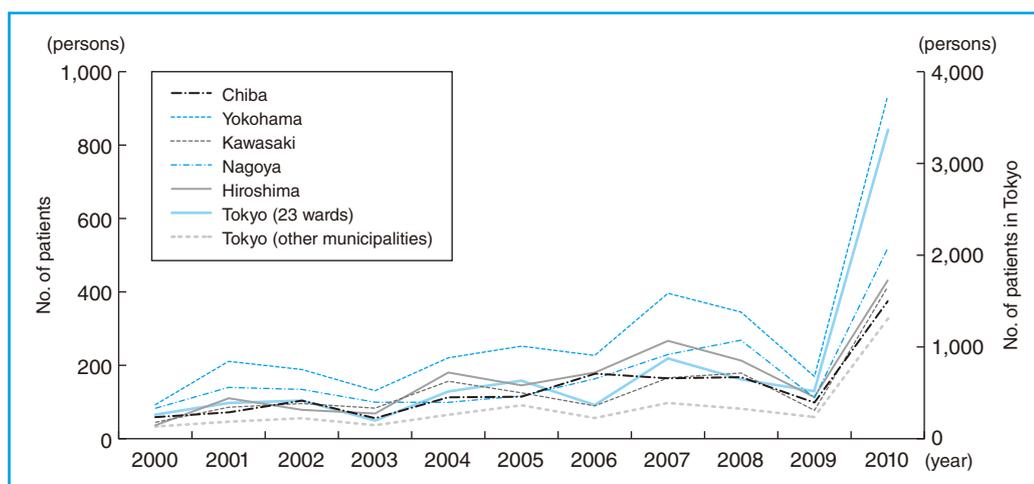


Fig. 1 Annual trend in the number of heat stroke patients in the cities

Their poor ability to control room temperature with the use of a room-air conditioner seemed to be a cause of this rather high incidence at home, in addition to their physical vulnerability and longer stay at home. On the other hand, heat stroke in 7–18 years of age frequently occurred while students were exercising in schools. In these cases, trainers and supervisors are asked for better awareness on the parts of heat stroke prevention. The incidence rates of heat stroke in young to middle-age individuals (19–39 years and 40–64 years) were lower than those in the elderly and elementary to junior or senior high

school students. The male-female difference was, however, greater in the former age groups because of hard works in males.

Annual changes in the number of patients and meteorological conditions

We focused on the relationship between some meteorological indices and annual changes in the incidence of heat stroke.

Table 1 shows the correlation between the total number of patients monthly, number of patients and thermal indices in Tokyo 23 wards, Nagoya City, and Osaka City. There was no distinct correlation between the thermal index and the total number of patients. In contrast, the monthly number of patients correlated significantly with certain thermal indices in all Tokyo, Nagoya, and Osaka.

These results show that, in regard to annual changes in the incidence of heat stroke, the total number of patients in the summer season cannot be explained well by meteorological conditions alone, whereas monthly changes in the number of patients correlate markedly with meteorological conditions including the monthly average of daily maximum temperature. Monthly or shorter changes in the number of patients well correlated to some meteorological indices.

Figure 3 shows the number of patients and the monthly average of daily maximum tempera-

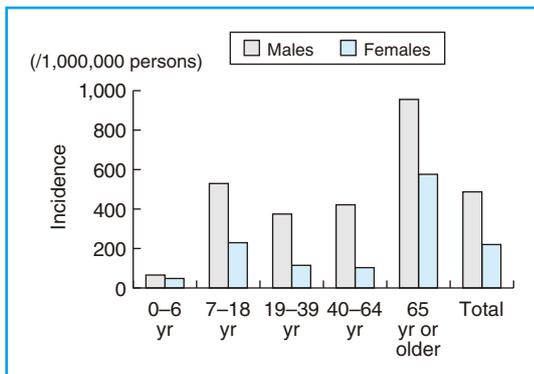


Fig. 2 Incidence of heat stroke by gender and age group (all cities in 2010)

Table 1 Correlations between thermal indices and numbers of patients

	Tokyo (23 wards)		Nagoya City		Osaka City		
	Total no. of patients	Monthly no. of patients	Total no. of patients	Monthly no. of patients	Total no. of patients	Monthly no. of patients	
Monthly mean of daily maximum temperature	May	0.042 (0.084)	0.236 (0.53)	-0.154 (0.032)	0.297 (0.299)	-0.636 (-0.325)	-0.293 (0.356)
	June	0.446 (0.148)	0.428 (0.224)	0.259 (-0.137)	0.574 (0.493)	-0.287 (-0.491)	0.619 (0.647)
	July	0.177 (-0.096)	0.433 (0.775)	0.107 (0.012)	0.470 (0.653)	0.111 (0.164)	0.634 (0.749)
	Aug.	0.618 (0.463)	0.712 (0.621)	0.360 (0.336)	0.407 (0.348)	0.611 (0.252)	0.679 (0.492)
	Sept.	0.417 (0.175)	0.480 (0.695)	0.398 (-0.235)	0.680 (0.616)	0.300 (-0.115)	0.533 (0.737)
	May-Sept.	0.530 (0.189)		0.362 (0.056)		0.231 (-0.061)	
	July-Aug.	0.431 (0.113)		0.253 (0.165)		0.445 (0.285)	
No. of hot days	≥30°C	0.475 (0.182)		0.290 (-0.112)		0.080 (-0.171)	
	≥31°C	0.506 (0.164)		0.405 (0.026)		0.333 (-0.055)	
	≥32°C	0.461 (0.043)		0.434 (0.118)		0.580 (0.113)	
	≥33°C	0.612 (-0.089)		0.519 (0.235)		0.465 (0.029)	
	≥34°C	0.724 (0.129)		0.482 (0.253)		0.622 (0.241)	
	≥35°C	0.742 (0.365)		0.575 (0.337)		0.702 (0.229)	

Correlation coefficients were obtained for 2000–2010 in Tokyo and Nagoya, and for 2002–2010 in Osaka. Numerical values in parentheses represent 2000–2009 for Tokyo and Nagoya and 2002–2009 for Osaka.

ture in Tokyo 23 wards in 2007 and 2010. Comparison of July in 2007 and 2010 showed marked differences in the monthly average of daily maximum temperature (27.4°C in 2007 to 31.6°C in 2010) and the number of extremely hot days defined by a maximum daily temperature 35°C or higher (0 day to 4 days). The marked increase in patients (from 47 to 1,226 individuals) from heat stroke in July might be explained by these meteorological conditions. However, in August, the number of patients increased dramatically (from 744 to 1,599 individuals) despite the absence of marked differences in the maximum temperature (monthly average of daily maximum temperature: from 33.0°C to 33.5°C), number of extremely hot days (7 days to 6 days), suggesting the involvement of factors other than the daily maximum temperature.

Relationship between daily number of patients and meteorological conditions

Figure 4 shows the daily number of patients and the maximum daily temperature from May 1st to September 30th in Tokyo 23 wards and Osaka City in 2010. There were large peaks in late-July and mid-August in both cities in accordance with the appearance of extremely hot days. Although there were extremely hot days from late August through early September, there was no large peak during this period, in contrast to the tem-

perature patterns in late-July or mid-August.

Figure 5 shows the incidence of heat stroke (number of patients per 1,000,000 persons•day) in relation to the maximum daily temperature in the Kanto area. Patients developed heat stroke when the maximum temperature reached approximately 28°C, and the incidence increased rapidly when the temperature exceeded 31°C. Although similar trends were seen in all cities, there were considerable differences in the incidences among cities.

As shown in Fig. 5, the incidence of heat stroke along with increases in temperature could be approximated by an exponential function. An estimate equation was developed to estimate the number of patients on a particular day, using the maximum temperature on that day and the previous day as explanatory variables chosen from among various combinations. The results of this estimation are shown in Fig. 6.

The late-July peak and early-summer peak were underestimated, whereas the moderate peak in early September was overestimated. This would appear to represent the consequences of acclimatization to ambient heat (many patients experienced heat stroke in the early period of summer because they could not well acclimatize, while fewer cases developed late-summer because of acclimatization to the heat).

We also examined meteorological elements

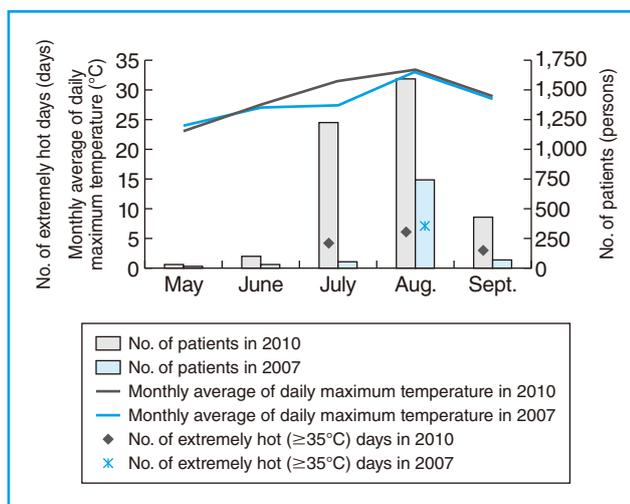


Fig. 3 Comparison of daily maximum temperature and the number of patients in 2007 and 2010

other than the maximum temperature on the day of heat stroke occurrence and that of the previous day. There was the issue of inadequate power of explanation because the contribution of the maximum temperature on the day of

occurrence to the heat stroke was very large, and because other meteorological elements (minimum temperature, the previous day's maximum temperature, and temperature difference from the previous day) correlated strongly with the

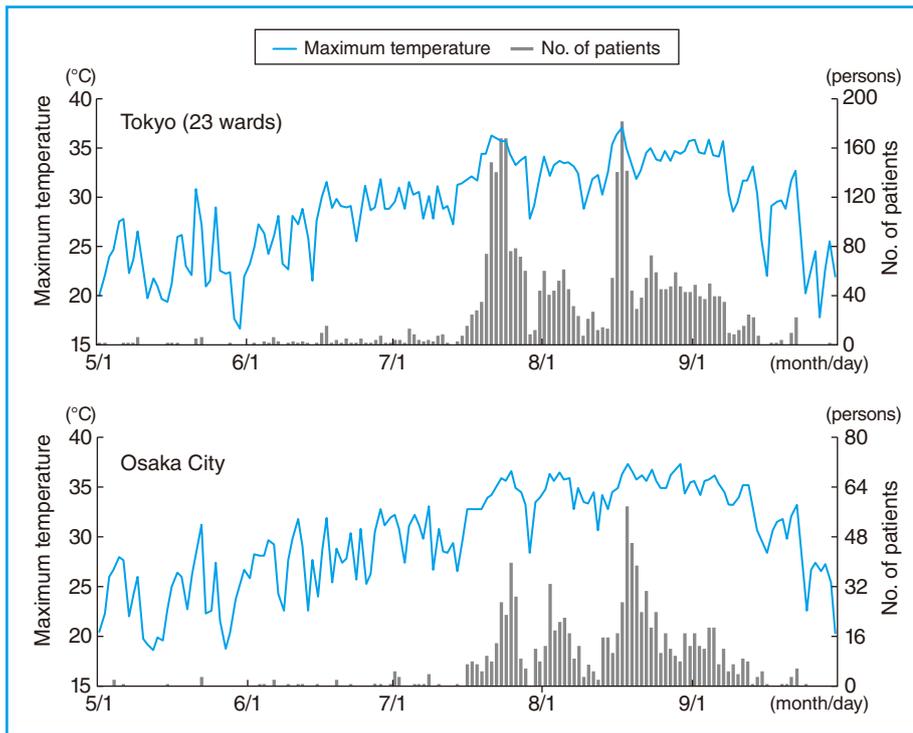


Fig. 4 Daily occurrence of heat stroke

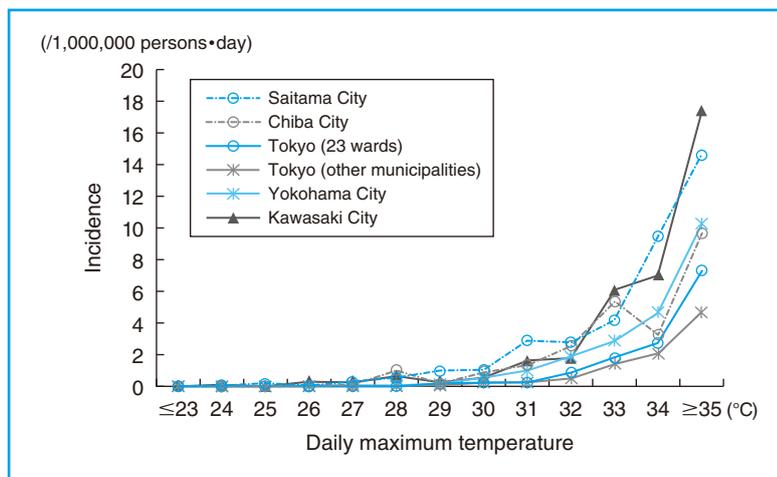


Fig. 5 Incidence of heat stroke in relation to the daily maximum temperature (2010)

maximum temperature on the day of occurrence.

Figure 7 shows the incidences of heat stroke in relation to the daily maximum temperature and to the daily maximum WBGT in Tokyo 23 wards, Nagoya City, Niigata City, and Osaka City. There were large differences in the incidence of heat stroke among the 4 cities when the daily maximum temperature reached 30°C or higher, suggesting the influences of factors other than temperature (relative humidity, amount of global solar radiation, wind velocity, etc.). As for Niigata City, where the incidence of heat stroke by the daily maximum temperature was highest, the relative humidity was 5–9% higher than those in

other cities in the summer of 2010. This roughly corresponds to 1°C as WBGT. In addition, this city was characterized by a low wind velocity and a high amount of global solar radiation. These findings were consistent with the smaller differences among the incidences of heat stroke by the daily maximum WBGT among localities except at 32°C.

Conclusion

Based on the data from Information System on Heat Stroke Patients, the current situation of heat stroke patients in this country has been

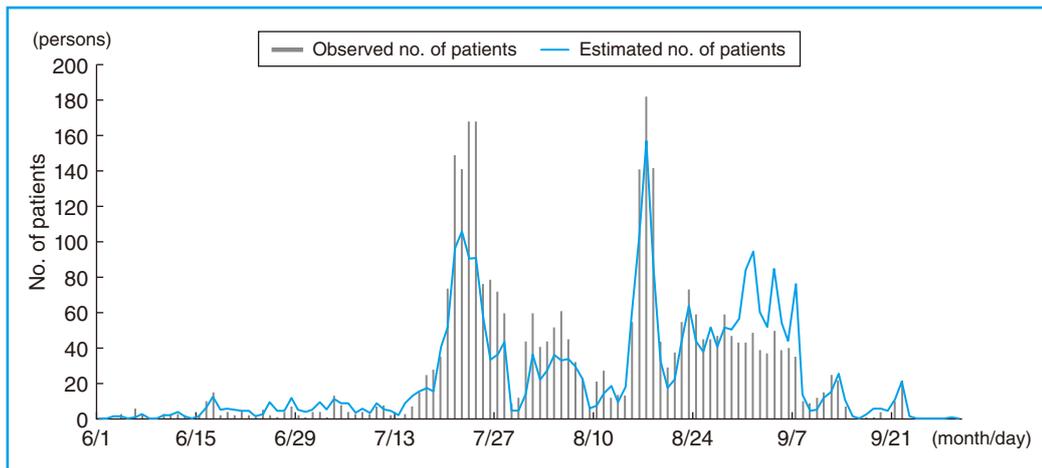


Fig. 6 Observed and estimated daily numbers of heat stroke patients

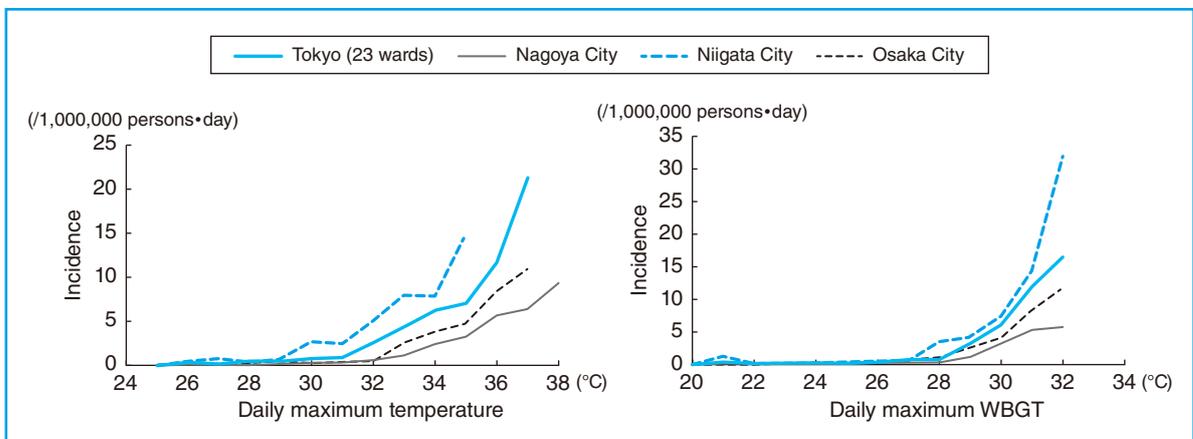


Fig. 7 Incidences of heat stroke in relation to the daily maximum temperature and the daily maximum WBGT (2010)

showed, and annual changes in the number of heat stroke patients and the relationship between the number of patients per day and meteorological conditions have been discussed. There was a strong relation between monthly or daily changes in the incidence of heat stroke and meteorological conditions, particularly the daily maximum temperature on the day of occurrence. In addition, it was shown that WBGT can serve as a useful index for heat stroke occurrence. On

the other hand, the presence of other variables, not explainable by the daily maximum temperature or WBGT, was also indicated.

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