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ORIGINAL ARTICLE

Seasonal variations of weather conditions on acute myocardial infarction onset: Oita AMI Registry

Hidefumi Akioka[1] · Kunio Yufu[1] · Yasushi Teshima[1] · Kyoko Kawano[1] · Yumi Ishii[1] · Ichitaro Abe[1] · Hidekazu Kondo[1] · Shotaro Saito[1] · Akira Fukui[1] · Norihiro Okada[1] · Yasuko Nagano[1] · Tetsuji Shinohara[1] · Mikiko Nakagawa[1] · Masahide Hara[1] · Naohiko Takahashi[1]

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Abstract

The onset of acute myocardial infarction (AMI) has been reportedly related to weather conditions. The aim of this study was to investigate the impact of weather conditions on AMI onset. Our study population consisted of 274 patients enrolled in the Oita AMI Registry who were admitted with AMI between June 2012 and May 2013. We divided the 365 days of the year into the four seasons: spring (March, April, May), summer (June, July, August), autumn (September, October, November), and winter (December, January, February). We classified each day as a day of onset of AMI (onset day) or a day of non-onset of AMI (non-onset day). Information on maximum temperature, minimum temperature, mean humidity, and mean atmospheric pressure was obtained from the Japan Meteorological Agency. In summer, the temperatures and intraday temperature differences were significantly lower on onset days than on non-onset days. Receiver operating characteristic analysis for predicting AMI onset in each season showed that the maximum temperature 2 days before AMI onset in summer had the largest area under the curve (AUC = 0.72, $p = 0.0005$). Our analysis demonstrated that there exist specific weather conditions that influence AMI onset in each season in Oita prefecture. AMI onset in summer was particularly associated with the maximum temperature 2 days before AMI onset.

Keywords Oita AMI Registry · Acute myocardial infarction · Weather conditions · The maximum temperature 2 days before AMI onset

Introduction

Several reports have shown that the occurrence of acute myocardial infarction (AMI) shows a seasonal variation, with a peak in the winter season and the lowest rate during the summer months [1–5]. It has been assumed that this is due to cold temperatures during the winter months, which affect platelet numbers, arterial blood pressure, fibrinogen, and other factors [6]. However, AMI also reportedly often occurs in summer when temperature and humidity are high and atmospheric pressure is low. No consensus on this question has been reached due to regional differences in geological conditions and living environments [7]. AMI is triggered by physiological factors stimulating the sympathetic nervous system and catecholamine release, and is also attributed to weather conditions such as temperature, humidity, atmospheric pressure, and others [8–12]. The aim of this study was to investigate the impact of seasonal weather conditions on the onset of AMI in Oita prefecture.

✉ Kunio Yufu
yufukuni@oita-u.ac.jp

1 Department of Cardiology and Clinical Examination, Faculty of Medicine, Oita University, 1-1 Idaigaoka, Hasama, Yufu, Oita 879-5593, Japan

Materials and methods

Study population

Acute myocardial infarction data were obtained from the Oita AMI Registry. Our study population consisted of 274 patients enrolled in the Oita AMI Registry who were admitted with AMI to 20 institutions between June 2012 and May 2013.

Meteorological factors

We divided the 365 days of the year into the four seasons: spring (March, April, May), summer (June, July, August), autumn (September, October, November), and winter (December, January, February). We classified each day as a day of onset of AMI (onset day) or a day of non-onset of AMI (non-onset day). Meteorological variables were obtained from the Japan Meteorological Agency. We investigated temperatures (average, maximum, and minimum), intraday temperature differences (minimum temperature divided by maximum temperature), average atmospheric pressure, and average humidity on the onset day (0-day) and at 1 day (1-day) and 2 days (2-day) before AMI onset. Patients provided informed consent for their participation in the study.

Compliance with ethical standards

All procedures performed in the study involving human participants were in accordance with the ethical standards of each institutional research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Statistical analysis

Data are presented as mean ± SD. The Chi-square test was used for categorical variables, and analysis of variance (ANOVA) was used for continuous variables. Differences between two groups were analyzed by Student's *t* test. Sensitivity and specificity for predicting AMI onset were calculated by receiver operating characteristic (ROC) analysis. Pairwise analysis was used for comparison of the ROC curves. All computations were performed with JMP (JMP version 11, SAS, Cary, NC, USA) running under Windows 8 (Microsoft, Redmond, WA, USA).

Results

Baseline characteristics

Basic characteristics of the patients enrolled are shown in Table 1. The mean age of the patients was 71 ± 12 years, and 65 (24%) were women. On average women were older than men (78 ± 9.0 vs. 69 ± 12 years, $p < 0.001$). Current smoking status was higher in men than in women (41 vs. 14%, $p < 0.001$), and we found no significant differences between women and men with respect to the prevalence of hypertension, diabetes mellitus, or dyslipidemia.

Seasonal distribution

Figure 1 shows the seasonal distribution of AMI onset days. Among the four seasons, AMI onset was most frequently observed in summer. However, the difference of association between AMI onset and a seasonal distribution was not significant.

AMI onset and meteorological factors in spring

Table 2 shows the analysis of the data for spring. The average temperatures on 1-day (13.6 ± 4.3 vs. 15.7 ± 4.5 °C,

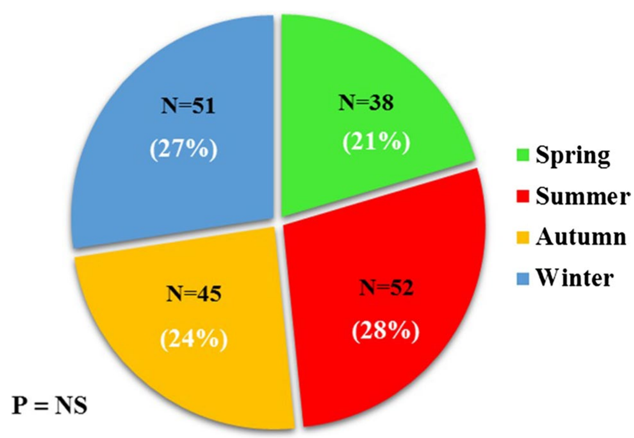

Fig. 1 Seasonal distribution of AMI onset days

Table 1 Comparison of baseline characteristics of AMI patients between men and women

	Total (*N* = 274)	Men (*N* = 209)	Women (*N* = 65)	*p*
Age	71 ± 12	69 ± 12	78 ± 9.0	< 0.001
Coexisting conditions				
Current smoking	94 (34%)	85 (41%)	9 (14%)	< 0.001
Hypertension	187 (68%)	137 (66%)	50 (78%)	0.06
Diabetes	96 (35%)	76 (36%)	20 (31%)	0.4
Dyslipidemia	157 (57%)	119 (57%)	38 (58%)	0.8

Table 2 Comparison between AMI onset and meteorological factors in spring

	Onset days ($N=38$)	Non-onset days ($N=54$)	p	Sensitivity	Specificity	AUC
Average temperature (°C)						
2-day	13.9 ± 4.2	15.3 ± 4.6	NS	81	39	0.58
1-day	13.6 ± 6.3	15.7 ± 4.5	0.025	68	63	0.63
0-day	13.7 ± 4.6	15.8 ± 4.3	0.032	66	63	0.64
Maximum temperature (°C)						
2-day	18.7 ± 4.9	21.0 ± 4.9	NS	82	41	0.6
1-day	18.6 ± 4.9	20.9 ± 4.9	0.027	71	61	0.64
0-day	18.6 ± 5.3	20.9 ± 4.5	0.026	55	78	0.64
Minimum temperature (°C)						
2-day	9.3 ± 4.4	10.1 ± 5.1	NS	82	31	0.53
1-day	8.6 ± 4.5	10.8 ± 4.9	0.032	66	57	0.62
0-day	9.0 ± 4.6	10.8 ± 4.9	NS	66	56	0.6
Intraday temperature difference (°C)						
2-day	9.4 ± 3.2	10.5 ± 3.1	NS	66	63	0.61
1-day	9.9 ± 2.9	10.0 ± 3.4	NS	42	70	0.52
0-day	9.6 ± 3.2	10.2 ± 3.3	NS	84	28	0.54
Average humidity (%)						
2-day	65.3 ± 12.3	63.7 ± 11.3	NS	26	85	0.51
1-day	62.7 ± 11.4	65.6 ± 12.0	NS	39	81	0.57
0-day	63.1 ± 12.7	65.6 ± 11.2	NS	26	89	0.57
Average atmospheric pressure (hpa)						
2-day	1012.2 ± 6.1	1013.2 ± 5.0	NS	32	93	0.55
1-day	1013.3 ± 5.9	1012.4 ± 5.0	NS	71	48	0.51
0-day	1013.5 ± 5.0	1012.0 ± 5.8	NS	66	61	0.59

AMI acute myocardial infarction, *0-day* day of AMI onset, *1-day* 1 day before AMI onset, *2-day* 2 days before AMI onset

$p=0.025$) and 0-day (13.7 ± 4.6 vs. 15.8 ± 4.3 °C, $p=0.032$) were significantly lower on onset days than on non-onset days. The maximum temperatures on 1-day (18.6 ± 4.9 vs. 20.9 ± 4.9 °C, $p=0.027$) and 0-day (18.6 ± 5.3 vs. 20.9 ± 4.5 °C, $p=0.026$) were significantly lower on onset days than on non-onset days. The minimum temperatures on 1-day were significantly lower on onset days than on non-onset days (8.6 ± 4.5 vs. 10.8 ± 4.9 °C, $p=0.032$). There were no significant differences in intraday temperature and average atmospheric pressure differences between onset and non-onset days.

AMI onset and meteorological factors in summer

Table 3 shows the analysis of the data for summer. The average temperatures on 2-day (24.4 ± 3.0 vs. 26.4 ± 2.8 °C, $p=0.0017$), 1-day (24.6 ± 3.2 vs. 26.5 ± 2.3 °C, $p=0.0021$), and 0-day (25.0 ± 3.0 vs. 26.2 ± 2.7 °C, $p=0.029$) were significantly lower on onset days than on non-onset days. The maximum temperatures on 2-day (27.9 ± 3.9 vs. 30.1 ± 3.8 °C, $p=0.0005$), 1-day (28.1 ± 4.4 vs. 30.9 ± 3.1 °C, $p=0.001$), and 0-day (28.7 ± 4.1 vs. 30.4 ± 3.7 °C, $p=0.049$) were significantly lower on onset days than on non-onset days. The minimum temperatures on 2-day (21.9 ± 2.7 vs. 23.3 ± 2.5 °C, $p=0.013$), 1-day (22.1 ± 2.6 vs. 23.2 ± 2.6 °C, $p=0.03$), and 0-day (22.1 ± 2.8 vs. 23.4 ± 2.2 °C, $p=0.021$) were significantly lower on onset days than on non-onset days. The intraday temperature differences on 2-day (6.0 ± 2.7 vs. 7.6 ± 2.4 °C, $p=0.0051$) and 1-day (6.0 ± 2.8 vs. 7.7 ± 2.3 °C, $p=0.0031$) were significantly lower on onset days than on non-onset days. The average humidity on 2-day (76.8 ± 7.5 vs. 74.8 ± 6.8%, $p=0.023$) and 1-day (78.6 ± 7.6 vs. 74.3 ± 6.3 °C, $p=0.0044$) was significantly higher on onset days than on non-onset days. There were no significant differences in average atmospheric pressure between onset and non-onset days.

AMI onset and meteorological factors in autumn

Table 4 shows the analysis of the data for autumn. The average humidity on 0-day was significantly higher on onset days than on non-onset days (68.4 ± 9.9 vs. 63.5 ± 8.2%, $p=0.013$). There were no significant differences between onset and non-onset days in meteorological variables except for average humidity on 0-day.

Table 3 Comparison between AMI onset and meteorological factors in summer

	Onset days ($N=52$)	Non-onset days ($N=40$)	p	Sensitivity	Specificity	AUC
Average temperature (°C)						
2-day	24.4 ± 3.0	26.4 ± 2.8	0.0017	60	77	0.69
1-day	24.6 ± 3.2	26.5 ± 2.3	0.0021	40	90	0.68
0-day	25.0 ± 3.0	26.2 ± 2.7	0.029	69	57	0.64
Maximum temperature (°C)						
2-day	27.9 ± 3.9	30.1 ± 3.8	0.0005	71	77	0.72
1-day	28.1 ± 4.4	30.9 ± 3.1	0.01	46	85	0.69
0-day	28.7 ± 4.1	30.4 ± 3.7	0.049	67	60	0.62
Minimum temperature (°C)						
2-day	21.9 ± 2.7	23.3 ± 2.7	0.013	63	70	0.65
1-day	23.3 ± 2.5	22.1 ± 2.6	0.03	56	75	0.62
0-day	22.1 ± 2.8	23.4 ± 2.2	0.021	44	83	0.63
Intraday temperature difference (°C)						
2-day	6.0 ± 2.7	7.6 ± 2.4	0.0051	69	62	0.67
1-day	6.0 ± 2.8	7.7 ± 2.3	0.0031	52	80	0.67
0-day	6.6 ± 2.9	7.0 ± 2.5	NS	65	50	0.54
Average humidity (%)						
2-day	76.8 ± 7.3	74.8 ± 6.8	0.023	60	65	0.63
1-day	78.6 ± 7.6	74.3 ± 6.3	0.0044	79	47	0.66
0-day	77.1 ± 7.7	75.9 ± 7.1	NS	46	70	0.54
Average atmospheric pressure (hpa)						
2-day	1007.3 ± 4.2	1007.3 ± 3.8	NS	58	50	0.5
1-day	1007.1 ± 4.1	1007.4 ± 3.8	NS	42	68	0.52
0-day	1007.4 ± 3.7	1006.8 ± 4.0	NS	67	47	0.54

AMI acute myocardial infarction, *0-day* day of AMI onset, *1-day* 1 day before AMI onset, *2-day* 2 days before AMI onset

AMI onset and meteorological factors in winter

Table 5 shows the analysis of the data for winter. The maximum temperature on 0-day was significantly higher on onset days than on non-onset days (11.3 ± 2.8 vs. 10.1 ± 2.5 °C, $p=0.041$). There were no significant differences between onset and non-onset days in meteorological variables except for maximum temperature on 0-day.

ROC analysis for predicting AMI onset among all seasons

The meteorological variables that were significantly associated with AMI onset in each season are summarized in Table 6. The predictive power of each meteorological variable on the occurrence of AMI was investigated and compared by area under the curve (AUC) on ROC analysis (Fig. 2). The greatest AUC for the meteorological factors in each season was 0.64 for maximum temperature on 0-day in spring, 0.72 for maximum temperature on 2-day in summer, 0.65 for average humidity on 0-day in autumn, and 0.58 for maximum temperature on 0-day in winter. The predictive valuable with the highest AUC of AMI onset among the four seasons was maximum temperature on 2-day in summer, and the cutoff values with the highest sensitivity and specificity were 71 and 77%, respectively (Fig. 2).

Association between the highest AUC of the meteorological variables in each season and the prevalence of coronary risk factors

Table 7 shows an association between the maximum temperature on 0-day in spring and the prevalence of coronary risk factors. We found the maximum temperature on 0-day of the highest AUC in spring was significantly higher in the patients with diabetes mellitus than in the patients without the disease (20.2 ± 5.3 vs. 17.6 ± 5.7 °C, p = 0.043). We found no significant associations in any of the other three seasons (Tables 8, 9, 10).

Discussion

Our analysis using the results of the Oita AMI Registry demonstrated that there exist specific weather conditions that influence AMI onset in each season. Among the four seasons,

Table 4 Comparison between AMI onset and meteorological factors in autumn

	Onset days (N=45)	Non-onset days (N=46)	p	Sensitivity	Specificity	AUC
Average temperature (°C)						
2-day	19.3 ± 5.2	18.7 ± 5.4	NS	67	43	0.51
1-day	19.3 ± 5.3	18.4 ± 5.2	NS	78	39	0.55
0-day	19.2 ± 5.0	18.2 ± 5.6	NS	89	28	0.54
Maximum temperature (°C)						
2-day	23.7 ± 5.5	23.3 ± 5.6	NS	67	48	0.52
1-day	23.8 ± 5.7	22.8 ± 5.2	NS	36	80	0.55
0-day	23.5 ± 5.2	22.7 ± 5.7	NS	78	37	0.53
Minimum temperature (°C)						
2-day	15.1 ± 5.8	14.8 ± 6.0	NS	56	50	0.5
1-day	15.1 ± 6.0	14.7 ± 5.8	NS	76	39	0.53
0-day	15.4 ± 5.7	13.8 ± 5.9	NS	91	33	0.59
Intraday temperature difference (°C)						
2-day	8.6 ± 2.7	8.5 ± 2.7	NS	56	61	0.52
1-day	8.7 ± 2.4	8.2 ± 2.5	NS	20	91	0.54
0-day	8.1 ± 2.7	8.9 ± 2.0	NS	58	70	0.61
Average humidity (%)						
2-day	65.7 ± 9.3	66.0 ± 10.4	NS	89	22	0.53
1-day	67.4 ± 8.9	64.2 ± 9.5	NS	73	50	0.62
0-day	68.4 ± 9.9	63.5 ± 8.2	0.013	56	70	0.65
Average atmospheric pressure (hpa)						
2-day	1014.1 ± 4.1	1013.0 ± 4.7	NS	67	54	0.6
1-day	1013.0 ± 4.7	1013.5 ± 4.3	NS	49	70	0.57
0-day	1013.4 ± 4.0	1014.6 ± 4.9	NS	44	76	0.6

AMI acute myocardial infarction, *0-day* day of AMI onset, *1-day* 1 day before AMI onset, *2-day* 2 days before AMI onset

in summer, low maximum/minimum temperature and high humidity were associated with the onset of AMI. Further ROC analysis revealed that AMI onset in summer was particularly associated with the maximum temperature 2 days before AMI onset. The association between AMI onset and meteorological factors has been examined in a large number of studies [13, 14]. Analyses have been reported from Korea; Hiroshima, Japan; and Germany [15–17]. The association is influenced by regional differences in geological conditions and living environments. Anyway, this is the first study to establish a relationship between weather conditions and AMI onset in Oita prefecture.

It has been reported that AMI is more frequent in winter than in other seasons [4, 8, 13, 18–20]. On the other hand, some studies have found that AMI frequently occurs in summer when temperature and humidity are high and atmospheric pressure is low [21]. In Korea, the number of AMI events and the case fatality rate of AMI varied by season, and both were highest in winter and lowest in summer [13–15, 20]. In Hiroshima, AMI tended to occur frequently on days with mean temperature < 10 °C and mean atmospheric pressure < 1005 hpa or when a cold front was passing [16, 17]. It has been reported that changes in the tone of the sympathetic nervous system, increases in blood pressure, myocardial oxygen consumption, platelets, factor IV, and fibrinogen, and decreases in antithrombin II in winter may play a role [11, 12]. Cold may increase the risk of respiratory infections by suppression of immune responses and direct effects on the respiratory tree; however, no association has been found between respiratory infections and coronary deaths during the cold season [7, 20]. Some studies have suggested that higher summer temperatures increase the rates of AMI onset and fatalities [4, 22–24]. The increased risk of fatal AMI in summer may be due to thermal stress. Thermal stress in the form of extremely cold or extremely hot temperatures may be associated with death due to AMI [14, 25]. Oita is located in southwest Japan in the Seto Inland climate and the climate of Japan's Pacific coast. Oita has a humid subtropical climate with hot summers and cool winters. We found a significant association of AMI onset with temperature and humidity in summer. Differences in climate may account for some of the differences between our results and those of other studies.

In northeastern China, AMI increased in summer when the temperature was high [21]. In Kagoshima prefecture, Amiya et al. reported that F-days (days of frequent onset,

Table 5 Comparison between AMI onset and meteorological factors in winter

	Onset days (N=51)	Non-onset days (N=39)	p	Sensitivity	Specificity	AUC
Average temperature (°C)						
2-day	6.2 ± 2.5	6.8 ± 2.3	NS	46	69	0.56
1-day	6.8 ± 2.6	6.1 ± 2.3	NS	92	24	0.55
0-day	6.9 ± 2.5	6.1 ± 2.3	NS	37	79	0.57
Maximum temperature (°C)						
2-day	10.7 ± 2.8	10.8 ± 2.6	NS	96	13	0.5
1-day	11.0 ± 3.0	10.4 ± 2.3	NS	22	95	0.52
0-day	11.3 ± 2.8	10.1 ± 2.5	0.04	25	95	0.59
Minimum temperature (°C)						
2-day	10.7 ± 2.8	10.8 ± 2.6	NS	37	82	0.59
1-day	11.0 ± 3.0	10.4 ± 2.3	NS	22	87	0.51
0-day	11.3 ± 2.8	10.1 ± 2.5	NS	16	100	0.54
Intraday temperature difference (°C)						
2-day	8.4 ± 2.3	7.8 ± 2.5	NS	71	51	0.58
1-day	8.3 ± 2.4	8.0 ± 2.3	NS	86	28	0.54
0-day	8.0 ± 2.3	7.9 ± 2.1	NS	23	90	0.57
Average humidity (%)						
2-day	65.5 ± 11.9	65.6 ± 12.1	NS	71	44	0.52
1-day	65.7 ± 13.3	65.2 ± 9.9	NS	25	90	0.5
0-day	66.1 ± 11.9	64.4 ± 11.9	NS	65	54	0.56
Average atmospheric pressure (hpa)						
2-day	1020.7 ± 4.6	1020.0 ± 4.8	NS	57	59	0.55
1-day	1020.2 ± 4.1	1020.2 ± 5.4	NS	75	44	0.51
0-day	1019.9 ± 5.0	1020.7 ± 4.3	NS	23	93	0.54

AMI acute myocardial infarction, *0-day* day of AMI onset, *1-day* 1 day before AMI onset, *2-day* 2 days before AMI onset

Table 6 Weather conditions significantly related to AMI onset in each season

Spring	1-day	Low average temperature, low maximum temperature, low minimum temperature
	0-day	Low average temperature, low maximum temperature
Summer	2-day	Low average temperature, low maximum temperature, low minimum temperature Low intraday temperature difference, high average humidity
	1-day	Low average temperature, low maximum temperature, low minimum temperature Low intraday temperature difference, high average humidity
	0-day	Low average temperature, low maximum temperature, low minimum temperature
Autumn	0-day	High average humidity
Winter	0-day	High maximum temperature

AMI acute myocardial infarction, *0-day* day of AMI onset, *1-day* 1 day before AMI onset, *2-day* 2 days before AMI onset

defined as days with three or more patients admitted for AMI) appeared to occur when intraday temperature differences were great and when maximum and minimum temperatures were low [26]. Shea et al. reported that the cold pressor test induced coronary spasm and that unstable angina was exacerbated to AMI [27]. The same test has also been shown to increase coronary artery resistance, hematocrit, platelet count, and blood viscosity [11]. Our study found that the maximum, average, and minimum temperatures were significantly lower on onset days than on non-onset days in summer. The relationship between AMI and low temperature remains unclear, but previous studies have suggested that the mechanism is due to increased blood pressure, blood flow changes, and airway infection [28–30]. Panagiotakos et al. reported a linear correlation between the mean daily temperature and hospital admissions for acute coronary syndrome, with a 1 °C decline in the mean daily temperature resulting in a 5% increase in hospital admissions [31]. In addition, Pan et al. established a U-shaped correlation between the average

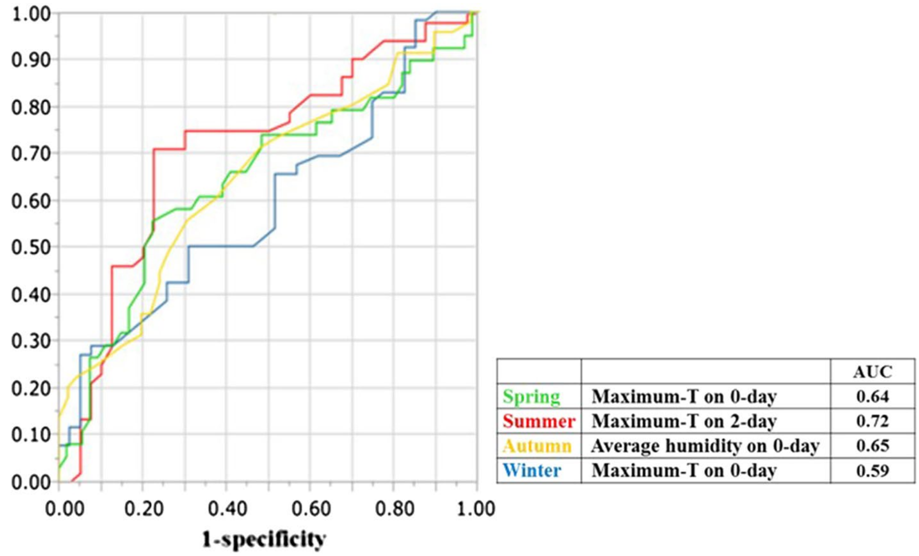

Fig. 2 Receiver operating characteristics curves for predicting AMI onset during all seasons. *0-day* day of AMI onset, *2-day* 2 days before AMI onset, *Maximum-T* maximum temperature

Table 7 Comparison between maximum temperature on 0-day and coronary risk factors in spring

Coronary risk factor	*N*	Maximum temperature on 0-day (°C)	*p*
Sex			
Male	47	18.7 ± 5.8	0.4
Female	17	17.3 ± 5.5	
Age			
Young group	18	19.6 ± 5.5	0.26
Elderly group	46	17.9 ± 5.5	
Current smoking			
Smoking (+)	24	18.8 ± 5.5	0.6
Smoking (−)	40	18.1 ± 5.9	
Hypertension			
Hypertension (+)	44	18.9 ± 5.6	0.21
Hypertension (−)	20	16.9 ± 5.9	
Diabetes mellitus			
Diabetes mellitus (+)	24	20.2 ± 5.3	0.043
Diabetes mellitus (−)	40	17.6 ± 5.7	
Dyslipidemia			
Dyslipidemia (+)	36	18.4 ± 6.2	0.98
Dyslipidemia (−)	28	18.4 ± 5.0	

Young group ≤ 65 years old, elderly group > 65 years old

Table 8 Comparison between maximum temperature on 2-day and coronary risk factors in summer

Coronary risk factor	*N*	Maximum temperature on 2-day (°C)	*p*
Sex			
Male	57	28.2 ± 4.0	0.61
Female	21	27.8 ± 3.9	
Age			
Young group	30	27.5 ± 3.7	0.29
Elderly group	48	28.5 ± 4.0	
Current smoking			
Smoking (+)	25	29.0 ± 4.5	0.15
Smoking (−)	53	27.7 ± 3.6	
Hypertension			
Hypertension (+)	54	27.8 ± 4.0	0.46
Hypertension (−)	24	28.9 ± 3.7	
Diabetes mellitus			
Diabetes mellitus (+)	25	28.8 ± 3.7	0.35
Diabetes mellitus (−)	53	27.9 ± 4.0	
Dyslipidemia			
Dyslipidemia (+)	49	28.6 ± 3.8	0.41
Dyslipidemia (−)	29	27.9 ± 4.0	

Young group≦65 years old, elderly group > 65 years old

temperature and coronary artery disease in Taiwan; in addition, they reported that the risk of coronary artery disease at 32 °C was 22% higher than the average temperature at 26–29 °C, and the risk increased by 2.8% per 1 °C reduction below 26–29 °C [32]. However, our analysis did not reveal the threshold effect of temperature (data not shown). Hence, the correlation between thermal stress and the AMI onset should be investigated in the future.

In our study, we observed a significant relationship between AMI onset and average humidity in summer and autumn. Average humidity was significantly higher on onset days than on non-onset days. Panagiotakos et al. found a positive association between relative humidity and hospital admissions for acute coronary syndrome [31].

The effects of atmospheric pressure on AMI are unknown. There was no relationship between atmospheric pressure and

Table 9 Comparison between average humidity on 0-day and coronary risk factors in autumn

Coronary risk factor	*N*	Average humidity on 0-day (%)	*p*
Sex			
Male	53	68.1 ± 9.5	0.93
Female	14	68.4 ± 7.9	
Age			
Young group	22	66.0 ± 7.2	0.18
Elderly group	45	69.2 ± 9.8	
Current smoking			
Smoking (+)	22	66.9 ± 9.2	0.40
Smoking (−)	45	68.8 ± 9.2	
Hypertension			
Hypertension (+)	40	69.1 ± 9.9	0.30
Hypertension (−)	27	66.8 ± 7.9	
Diabetes mellitus			
Diabetes mellitus (+)	22	69.7 ± 9.6	0.34
Diabetes mellitus (−)	45	67.4 ± 9.6	
Dyslipidemia			
Dyslipidemia (+)	43	67.9 ± 9.7	0.74
Dyslipidemia (−)	24	68.7 ± 8.2	

Young group ≤ 65 years old, elderly group > 65 years old

Table 10 Comparison between maximum temperature on 0-day and coronary risk factors in winter

Coronary risk factor	*N*	Maximum temperature on 0-day (°C)	*p*
Sex			
Male	52	11.7 ± 3.1	0.61
Female	13	11.2 ± 2.1	
Age			
Young group	26	11.1 ± 3.0	0.29
Elderly group	39	11.9 ± 2.8	
Current smoking			
Smoking (+)	23	11.5 ± 2.9	0.9
Smoking (−)	42	11.6 ± 3.0	
Hypertension			
Hypertension (+)	49	11.6 ± 2.6	0.86
Hypertension (−)	16	11.5 ± 3.8	
Diabetes mellitus			
Diabetes mellitus (+)	25	12.2 ± 3.0	0.21
Diabetes mellitus (−)	40	11.1 ± 2.9	
Dyslipidemia			
Dyslipidemia (+)	29	11.1 ± 2.8	0.22
Dyslipidemia (−)	36	12.0 ± 3.0	

Young group ≤ 65 years old, elderly group > 65 years old

AMI incidence in Italy [33]. In Hungary, changes in atmospheric pressure are greatest during the spring and autumn, when the seasonal average of AMI events is the highest. During the summer months, low AMI incidence was accompanied by a decreasing monthly average atmospheric pressure; however, no definite relationship could be found in this report [4, 19]. Based on the literature, it may be assumed that changes in atmospheric pressure also contribute to the development of ruptured plaques [4, 19]. AMI has been shown to occur more frequently as the atmospheric pressures get lower [16, 17, 34]. Wang et al. reported that AMI in Hiroshima (Japan) tends to occur frequently on days with mean atmospheric pressures < 1005 hpa [16]. However, Honda et al. reported that in Kumamoto (Japan), AMI occurrences are associated with high atmospheric pressures [35]. They suggested that AMI onsets might be associated with specific patterns of atmospheric pressure distribution wherein high pressures are common in West Japan and low pressures in East Japan [35]. However, an explanation for these results is unknown. In our study, we did not find any significant associations between atmospheric pressure and AMI onset during any season. Our analyses for each season resulted in no significant associations between AMI onsets and the average atmospheric pressures. This may be due to regional differences and differences in patients' backgrounds.

Our study shows a significant predictive value of the maximum temperature at 2 days before AMI onset in Oita. Previous studies in Japan have shown that lower minimum temperatures in Kumamoto and intraday temperature differences in Kagoshima on day 2 preceding onset were associated with days of frequent AMI onset [26, 35]. Forecasting may help us to reduce the time of the door-to-balloon to improve the hospital mortality rate [36]. Predicting AMI onset based on meteorological variables such as temperature, atmospheric pressure, and humidity on the day of likely onset might be useful, but if AMI onset can be predicted based on meteorological variables 1 or 2 days before onset, forecasting will prove highly beneficial in clinical settings.

As shown in Table 7, the maximum temperature on 0-day of the highest AUC of the meteorological variables in spring was significantly higher in the patients with diabetes mellitus than in the patients without the disease. In this regard, Blauw et al. have stated that on average, every 1 °C increase in temperature increases the age-adjusted diabetes incidence by 0.314 per 1000 [37]. And Sakura et al. have shown that HbA_{1C} levels are highest in winter–spring and lowest in summer–autumn in most patients [38]. Taken together, it is conceivable that maximum temperatures may alter glycemic control in patients with diabetes mellitus and are associated with the onset of AMI in spring. As shown in Table 2, the maximum temperature of AMI onset days was lower than that of non-onset days for all study subjects in spring. Notably, the highest AUC for the metrological factors in spring was the maximum temperature on 0-day in spring. Remarkably, as presented in Table 7, the maximum temperature on 0-day was significantly higher in patients with diabetes mellitus than that without (20.2 ± 5.3 vs. 17.6 ± 5.7 °C; $p = 0.043$). Although the specific mechanism remains unclear, this inconsistent result could be attributed to the hypothesis that although AMI tends to develop more frequently at the day with the low maximum temperature in spring, diabetic patients can develop AMI even on the day with the higher maximum temperature.

Study limitations

Our study has several limitations. First, the period of enrollment in Oita AMI registry was set at 1.5 years; therefore, the number of case was small, especially among young women. Second, we were not able to evaluate the relationship between AMI onset and the environmental factors present in Oita. In fact, Kojima et al. have reported that Asian dust is a potential trigger for the onset of AMI in exposed patients, and that the incidence of AMI may increase the day after the dust exposure event in Kumamoto [39]. Finally, a more complex model should be developed to adjust other meteorological variables that affect the AMI onset. Nevertheless, our simple method to compare the meteorological factors, including temperature, between onset days and non-onset days could have a high potential to evaluate the correlation between temperature and the onset of several diseases.

Conclusion

Our analysis demonstrated that there exist specific weather conditions that influence AMI onset in each season in Oita prefecture. ROC analysis revealed that AMI onset in summer was particularly associated with the maximum temperature 2 days before AMI onset, which may favor the development of vulnerable coronary plaque.

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Compliance with ethical standards

Conflict of interest The authors have no conflict of interest.

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