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Variation in fracture risk by season and weather: A comprehensive analysis across age and fracture site using a National Database of Health Insurance Claims in Japan

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ABSTRACT

Although age- and season-specific effects on fracture risk have been reported, the effects of seasonality across different age groups and for different fracture sites have not yet been clarified. Therefore, our study aimed to comprehensively investigate the effects of seasonality on fracture risk across age and fracture sites using a large-scale population database of fracture incidence.

Fracture data were accumulated over a 3-year period in the region of Tokyo and in surrounding areas, which accounts for a total population of 42 million. Information on fracture occurrence, fracture site, and patient demographics were obtained from the National Database of Health Insurance Claims and Specific Health Checkups of Japan (NDB).

Over the study period, 508,051 fractures were identified across the following five age groups: 0–19, 20–39, 40–64, 65–79, and 80+ years. The incidence rate for fractures in 10 site groups was calculated. Fracture risk was the highest in the spring and autumn for children aged 0–19 years and was the highest in the winter for elderly individuals (65–79 and 80+ years). Toe fractures, which occurred more frequently in the summer, were the most notable exception. The risk of fracture of the distal radius and hip was associated with daily temperature and rainfall and was elevated on days with a mean temperature higher than that of the previous day.

Fracture risk exhibited seasonal variations that differed between children and elderly individuals and between toe fractures and fractures at other sites. These findings can help us understand the epidemiology of fractures and develop preventive strategies, as well as aid in the allocation of healthcare resources.

1. Introduction

Fractures are a major public health burden with serious consequences for individuals at all ages, especially the elderly [1,2]. A better understanding of the epidemiology of fractures, especially associated risk factors, would be relevant to improve our understanding of the etiology of fractures and, potentially, to inform preventive strategies, such as patient education. The epidemiology of fractures is also related to health care planning. As fractures require a multidisciplinary treatment approach, ranging from surgery to physiotherapy and rehabilitation [3,4], appropriate allocation of healthcare resources for the treatment of fractures is expected, with consideration of the variation in the incidence rate of fractures according to day of the week and season.

Seasonal effects have been reported for specific types of fractures, with a higher incidence rate for hip [5–13] and distal forearm fractures [7,14] among elderly individuals during the winter in northern European countries, with this higher incidence being attributed to a higher risk for falls on snow and ice [7]. A similar increase in fracture incidence, however, has been reported in the winter in countries that do not have snow or ice, which has been explained by a decrease in the hours of sunshine, vitamin D deficiency, and lower temperatures [10,11]. However, most of these previous studies evaluated incidence rates using regional registries for specific diseases [7,12,14] or through a review of medical records from specific hospitals [15–17], with both

Abbreviations: CI, confidence interval; GLM, generalized linear modeling; ICD-10, International Statistical Classification of Diseases, Tenth Edition; NDB, National Database of Health Insurance Claims and Specific Health Checkups of Japan

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of these techniques requiring substantial effort to collect cases. Moreover, the relationship between the incidence of fractures and climate has been investigated only for a few common fractures, suggesting that collecting cases of fractures at rarer sites is more difficult.

The Ministry of Health, Labor and Welfare in Japan implemented a database of all public health insurance claims in 2009. This National Database of Health Insurance Claims and Specific Health Checkups of Japan (NDB) includes all medical procedures and physicians' diagnoses as medical claim data [18]. As Japan has universal health coverage, with local governments providing payment for the < 2% of the population who are on welfare, and with exceptions of accidents covered by automobile liability insurance or worker's accident compensation in prior to health insurance, the NDB is considered to be representative of almost all health claims in Japan. Therefore, the use of the NDB is appropriate to evaluate season-and weather-specific effects on fracture incidence, providing data for a large population and including not only common fractures, but also fractures at other sites.

Our study aimed to comprehensively investigate effects of seasonality on fracture risk across age and fracture site using a large-scale population database of fracture incidence.

2. Materials and methods

2.1. Identification of cases

We identified fracture cases from the NDB for one geographic area, Kanto, which includes Tokyo and its surrounding six administrative regions, with a population of about 42 million. All fracture cases treated under public health insurance during the study period (area during April 1, 2013 to March 31, 2016) in any hospital or clinic in the Kanto area were included in the study. Fracture cases were selected based on any treatment code provided both in outpatient and inpatient settings for a fracture recorded on the claim, which includes closed reduction of fracture, percutaneous pinning of fracture, open reduction and internal fixation of fracture, open reduction of intra-articular fracture, arthrodesis, hemiarthroplasty, and total arthroplasty (Supplemental Appendix 1). Fracture sites were categorized as follows based on the diagnosis documented on the claim by the provider according to the clinical diagnosis: 1) clavicle, scapula, or humerus; 2) radius or ulna; 3) bones of the hand; 4) femur; 5) patella, tibia or fibula; 6) ankle; and 7) bones of the foot. Fractures of the distal radius and hip, based on the documented diagnosis on the claim by the provider as well, were analyzed independently from these groups, considering their high prevalence and clinical importance. Toe fractures were also distinguished because of the difference in seasonal epidemiological pattern from fractures to other bones of the foot. Sites of non-peripheral fractures, such as the skull, rib, sternum, vertebrae, or pelvis, were not included in this analysis because inclusion criteria based on the treatment codes would not efficiently identify the cases of these fractures.

Fractures of the same group of sites for the same person during the study period were considered as a single case and identified by matching the claim using a previously described method [18]. Cases of multiple fractures were considered to be a single case when multiple fractures involved only one group of sites; otherwise a fracture of multiple sites were considered to be a separate case for each group of sites. Recurrent fracture cases in one group of sites during the study period were excluded. Cases in which documentation of diagnosis or application of treatment procedure was > 2 weeks later than admission were excluded, in an attempt to exclude hospital-acquired cases of fractures, but to include the nosocomial fracture cases of which documentation of diagnosis or treatment procedures took place several days after the admission. As the claim data does not include the day of injury, the day of the first hospital/clinic visit was considered as a proxy for the day of fracture. For cases in which an individual visited an institution and was diagnosed with the same group of fracture within 2 weeks prior to the admission or actual treatment provided in other institution, the day of the earlier visit was considered as the day of injury; otherwise the date of admission (for inpatient) or first visit (for outpatient) to the institution which provided actual treatment was considered as the day of injury. We excluded cases in which the first hospital/clinic visit occurred during the first and last 2 weeks of the study period due to the incomplete information of the multiple visits made to other hospitals/clinics for these periods. Therefore, our final analysis included fractures in which the first hospital/clinic visit was made between April 15, 2013 and March 17, 2016.

2.2. Weather data

The area for this study was within 100 km from the Tokyo District Meteorological Observatory, comprised mostly of the Kanto plain, with little variation in weather. Tokyo is located, geographically, in the northern Temperate Zone, with seasonal change in climate. Weather data was recorded by the Japanese Meteorological Agency, with this data being public [19]. Readings of daily average temperature (in °C), daily average wind speed (in m/s) and amount of rainfall (in mm), reported by the Tokyo District Meteorological Observatory, were considered as representative of the area. The mean overall temperature over the study period was 16.8 °C, with the highest average temperature occurring in August (27.8 °C) and the lowest in January (6.1 °C). Generally, there was less precipitation in winter than in summer.

2.3. Demographic data

The characteristics of the study population were obtained from the Ministry of Internal Affairs and Communication, with the population on October 1, 2014, the midpoint of the study period, considered as representative of our study population. To calculate the incidence rate per person-years, we divided the number of cases during the study period by the population of the area and the number of days of the study period and multiplied by 365 days. Considering that the border of the study area is largely rural in nature, the flow of patients into and out of the study area was assumed to be very small.

2.4. Statistical analysis

The number of fracture cases was accumulated on a daily basis, stratified by the group of fracture site, based on ICD-10 classification, and sub-classified into the following five age groups: (0–19, 20–39, 40–64, 65–79 and 80 + years). A more detailed analysis of the variation in fracture incidence rates by age and age groups of 10 years was also performed. Cases were aggregated by months and seasons, where seasons were defined, as follows, according to the definition by the Japanese Meteorological Agency: spring (March, April, May); summer (June, July, August); autumn (September, October, November); and winter (December, January, February).

To evaluate the seasonal variation in the incidence rate of fractures, we performed a Kruskal-Wallis test of the daily number of cases of fractures by season. If a significant seasonal variation was identified, the ratio of the crude incidence rate between peak and trough seasons was calculated. Confidence interval of the crude incidence rate was also presented where appropriate using generalized linear modeling (GLM) and Poisson regression analyses, with season as a single explanatory variable.

The association between daily weather and the incidence of fractures was evaluated for selected fractures that caused a high burden within each age group, using GLM and Poisson regression analyses. The dependent variable was the daily number of cases and the explanatory variables being the daily mean temperature, the difference in the daily mean temperature from the previous day, daily average wind speed, daily waterfall, and day of the week.

All analyses were performed using SPSS (version 24), with a P-value < 0.05 considered significant.

Table 1
Population of the area and the number of cases.

	Age group (years)	Population (in thousands)	Number of fracture cases	Annual rate per 1000 person-years
Male	0–19	3700	79,756	7.37
	20–39	5513	28,985	1.80
	40–64	7522	45,394	2.06
	65–79	3563	30,560	2.93
	80+	970	26,580	9.36
	Total	21,268	211,275	3.40
Female	0–19	3512	34,019	3.31
	20–39	5137	11,329	0.75
	40–64	7195	46,180	2.19
	65–79	3961	84,423	7.28
	80+	1714	120,825	24.09
	Total	21,519	296,776	4.71
Total	0–19	7212	113,775	5.39
	20–39	10,650	40,314	1.29
	40–64	14,717	91,574	2.13
	65–79	7524	114,983	5.22
	80+	2684	147,405	18.77
	Total	42,787	508,051	4.06

3. Results

The population in the study area (Tokyo and its six surrounding administrative areas) was 42,787 thousand (Table 1), with an approximately equal distribution of males and females. The smallest population was for the 0 to 19-year-old group, although this cohort for this age was sufficient (at 7212 thousand) for observation.

Over the study period, we identified 508,051 cases of fracture (Table 1). The risk of fracture was greater in males than females for the younger age groups (0–19 and 20–39 years), and greater in females for the older age groups. Overall, the crude risk of fracture was greater for females.

The incidence rate of fracture of 11 groups of fracture sites across age group, with 10-year interval, was shown in Table 2. The highest incidence for fractures is of the radius or ulna, among which distal radius fractures accounts for 103,641 cases, with an incidence rate of 82.8 per 100,000 person-year. The age-distribution of distal radius fractures was bimodal, with one peak in the age group of 10–19 years (incidence rate of 212.4 per 100,000 person-years) and a second peak in elderly individuals, with an incidence rate of 281.2 per 100,000 person-year for the age group ≥80 years.

Fractures of the hip were also very common, accounting for 119,379 cases. These fractures are uncommon in children, with the incidence increasing with age to become the most common site of fracture among individuals ≥80 years-old, with an incidence rate of 1112.0 per 100,000 person-year.

Risk pattern across age was different between fracture sites. Among the fractures with a bimodal pattern, fractures of clavicle, scapula, or humerus had a first peak in the age group of 0–9 years, while fractures of radius, ulna, fibula and tibia or bones of the foot had a first peak at age 10–19 years.

The association between fracture incidence and seasons is described in Table 3, with the association for children being distinct from the association for adults and the elderly. Among children, a significant seasonal effect on incidence rate was identified for all fracture sites, except the femur. For most of these sites, the incidence of fracture was higher in spring or autumn, with a low incidence in the winter or summer. The majority of fractures occurred in the spring. As an example, the incidence of fractures of clavicle, scapula, or humerus peaked in the spring, with a crude risk ratio of 1.43 (95% confidence interval (CI), 1.37–1.49), compared to the trough incidence rate in winter. Similarly, the risk of a distal radial fracture was 70% (relative risk (RR) 1.70, 95% CI 1.64–1.76) higher in the spring than winter. For both of these fracture sites, the incidence peaked in April to June, with a smaller peak in September to October. The trend for fractures of the bones of the hand was different, with the incidence being higher in autumn, increasing again in the spring. Toe fractures had a completely different incidence profile, with the incidence peaking in the summer, with a trough in winter.

In comparison to children, elderly individuals (the 65–79 and 80+ years age group) were at higher risk for fractures in winter. Significant seasonal effects were identified for all fracture sites, except fractures of the foot other than the toes, with the incidence rate for most of these sites peaking in winter. Specifically, in winter, the risk for distal radius fractures was 39% (RR, 1.39; 95% CI, 1.34–1.43) higher than in the spring for the age group 65–79 years and 31% (RR, 1.31; 95% CI, 1.26–1.36) higher than in the summer for the age group 80+ years, with the risk being specifically higher in January and February. Hip fractures had a similar seasonal profile, with a peak in winter and a trough in summer, with a winter-to-summer crude risk ratio of 1.43 (95% CI, 1.38–1.48) and 1.27 (95% CI, 1.24–1.29) for age group 65–79 and 80+ years, respectively. Although the RR for the winter compared to summer was larger for the 65–79 years age group than the 80+ years group, we must note that greater prevalence of hip fracture in age group 80+ would result in a greater absolute risk difference. The incidence profile for distal humerus fractures was different, with these fractures being the most common in autumn, although the difference in risk between autumn and winter was minimal. Similar to children, toe fractures were the most common in the summer; with the risk being 52% higher (RR, 1.52; 95% CI, 1.37–1.70) than in the spring for the age

Table 2
Number of cases and incidence rate by fracture site.

Fracture site	ICD-10 codes	Number of cases	Incidence rate (per 100,000 person-year)	Age group (years)								
				0–9	10–19	20–29	30–39	40–49	50–59	60–69	70–79	80+
Clavicle, scapula, or humerus	S42, S49.7	66,113	52.8	105.7	81.7	19.6	18.4	26.5	35.9	41.8	70.3	171.2
Radius or ulna												
Distal radius	S52.5	103,641	82.8	47.4	212.4	17.4	11.0	18.3	48.4	100.4	158.9	281.2
Other	S52.1-4/6-9, S59.7	37,070	29.6	52.1	93.4	10.7	8.7	10.1	14.3	23.7	37.2	69.0
Bones of the hand	S62, S69.7	63,614	50.8	30.2	218.6	40.5	30.5	31.6	31.7	30.0	38.1	56.9
Femur												
Hip	S72.0-2	119,379	95.4	0.2	0.8	0.9	1.8	4.4	14.5	44.7	156.3	1112.0
Other	S72.3-9, S79.7	8513	6.8	2.2	4.4	2.2	1.2	1.5	2.5	5.1	12.0	52.7
Patella, tibia, or fibula	S82.0-4/7/9, S89.7	40,081	32.0	19.1	51.7	14.2	14.2	20.1	29.4	40.9	53.2	71.9
Ankle	S82.5-6/8	25,165	20.1	9.9	39.2	13.4	11.6	15.1	22.2	25.5	26.5	23.3
Bones of the foot												
Toe	S92.4-5	18,394	14.7	7.9	37.0	7.0	11.0	13.7	19.9	14.9	11.9	10.5
Other	S92.0-3/6-9, S99.7	26,081	20.8	8.6	35.4	13.5	12.9	16.3	22.8	26.6	28.8	28.4

Table 3
Seasonal variation of fracture incidence across age and fracture site.

	Children Age 0-19 years				Adult Age 20-39 years				Adult Age 40-64 years			
	P-value for Seasonal Difference*	Peak Season**	Trough Season**	RR (Peak/Trough)***	P-value for Seasonal Difference	Peak Season	Trough Season	RR (Peak/Trough)	P-value for Seasonal Difference	Peak Season	Trough Season	RR (Peak/Trough)
Fracture sites												
Clavicle, scapula, or humerus	< 0.001	spring	winter	1.43	< 0.001	winter	autumn	1.29	0.005	winter	summer	1.12
Radius or ulna												
Distal radius	< 0.001	spring	winter	1.70	< 0.001	winter	autumn	2.08	< 0.001	winter	spring	1.49
Other	< 0.001	spring	winter	1.61	0.001	winter	summer	1.22	< 0.001	winter	summer	1.30
Bones of the hand	< 0.001	autumn	summer	1.23	0.036	summer	winter	1.12	0.241			
Femur												
Hip	0.489				0.267				< 0.001	winter	summer	1.26
Other	0.119				0.711				0.170			
Patella, tibia, or fibula	< 0.001	spring	summer	1.39	0.032	spring	autumn	1.13	< 0.001	winter	summer	1.52
Ankle	< 0.001	spring	summer	1.30	0.043	spring	summer	1.15	< 0.001	winter	summer	1.40
Bones of the foot												
Toe	< 0.001	summer	winter	1.56	< 0.001	autumn	winter	1.28	< 0.001	summer	winter	1.40
Other	< 0.001	autumn	summer	1.24	< 0.001	summer	winter	1.34	< 0.001	summer	winter	1.18

	Elderly Age 65-79 years				Elderly Age 80+ years			
	P-value for Seasonal Difference	Peak Season	Trough Season	RR (Peak/Trough)	P-value for Seasonal Difference	Peak Season	Trough Season	RR (Peak/Trough)
Fracture sites								
Clavicle, scapula, or humerus	< 0.001	winter	summer	1.24	< 0.001	winter	summer	1.29
Radius or ulna								
Distal radius	< 0.001	winter	spring	1.39	< 0.001	winter	summer	1.31
Other	0.012	winter	summer	1.20	0.014	autumn	summer	1.15
Bones of the hand	< 0.001	winter	summer	1.27	< 0.001	winter	summer	1.40
Femur								
Hip	< 0.001	winter	summer	1.43	< 0.001	winter	summer	1.27
Other	0.020	winter	spring	1.23	< 0.001	winter	summer	1.20
Patella, tibia, or fibula	< 0.001	winter	summer	1.48	< 0.001	winter	summer	1.38
Ankle	< 0.001	winter	summer	1.40	0.005	winter	summer	1.38
Bones of the foot								
Toe	< 0.001	summer	spring	1.52	< 0.001	summer	winter	1.47
Other	0.178				0.130			

RR = risk ratio; spring = March, April or May; summer = June, July or August; autumn = September, December or November; winter = December, January or February.

* P-value for seasonal difference is the result of analysis of variance for difference of daily number of cases across seasons.

** Peak and trough seasons indicate the season with highest and lowest incidence rate respectively.

*** RR(peak/trough) indicates the risk of the season with the highest incidence compared with the lowest.

group 65–79 years, and 47% (RR, 1.47; 95% CI, 1.21–1.79) higher than in the winter for the age group 80+ years. It was also notable that a winter peak was not observed in the risk of fractures of the radius and ulna, other than distal radius fractures for the age group 80+; for this latter age group, a small increase in risk was observed in the autumn compared with trough in the summer (RR, 1.15; 95% CI, 1.07–1.24), followed by winter.

The seasonal variation in the risk of fracture for adults (40 to 64 years age range) was similar to the profile for the elderly age group (65–79 and + 80 years), with fractures at most sites being the most common in winter, with a crude risk ratio of 1.1 to 1.5 compared to the season with the lowest risk. Fractures of foot bones were the most common in the summer.

Younger adults (20 to 39 years age group) showed less remarkable seasonal variation. There was no seasonal variation in the risk of fractures of the femur. However, seasonal variation of the risk for fractures of the distal radius was the most prominent in this age group, with the risk being 2.08 times higher (95% CI, 1.91–2.27) in winter than in autumn.

Results of the Poisson regression analysis for the association between number of cases of a distal radius fracture and daily weather are shown in Table 4. As the pattern of seasonal variation of fracture risk differed across age groups, from children to elderly, we investigated the association between weather and the risk of distal radius fracture, one of the most common fracture sites, regardless of age. For children, the risk of a distal radius fracture was the highest on days with a mean daily temperature between 15 °C and 24.9 °C, being lower on warmer or cooler days. The risk of these fractures in the elderly, by comparison, was higher on colder days. Of note, across all age groups, the risk for a distal radius fracture was lower on days colder than the previous day. The risk was also higher on windy days, although the effect of wind on fracture risk was minimal, overall. As well, the risk for this fracture was significantly lower on rainy days, except for a non-significant result for the 40 to 64 years age group.

The same analysis was performed for hip fractures for the elderly groups (65–74 and +80 years), due to the remarkable burden of these fractures in these age groups (Table 5). The risk for hip fractures was lower on days colder than the previous day. Of note, in these age groups, the risk for distal radius fractures was higher on colder days.

4. Discussion

We report the 3-year incidence profile of fractures for a large population cohort of > 40 million, providing a comprehensive analysis for variation in risk across fracture sites, age groups, and seasons. Our inclusion of all peripheral fracture sites is important, as most previous studies analyzed only major fractures, such as distal radius [7,14] and hip fractures [5–13]. Overall, the seasonal pattern of fracture risk was comparable at most fracture sites within an age group, with the risk for fractures being higher in the spring and autumn for children, and higher in winter for the elderly. This age difference in risk profile intuitively makes sense, as children tend to be more physically active in the moderate weather conditions in spring and autumn [20,21]. The lower risk of fractures in children in the summer likely reflects a decrease in physical activity in the hot weather and/or a decrease in social activity during the summer holidays. Further analysis of the incidence of distal radius fracture and daily weather conditions, excluding the usual period of summer holidays in Japanese schools, still revealed a lower risk on days in which the temperature exceeded 25 °C. Therefore, the decrease in the risk of distal radius fractures in children is not solely explained by holidays.

Previous studies suggested various reasons why the incidence of fractures in elderly individuals was higher in winter than any other season. Among these factors, slippery conditions during winter have been reported to be a major influence [7,22]. However, this hypothesis would not apply to our study because the accumulation of snow was rare in Tokyo and its surrounding area. This is in agreement with other studies that have reported an increased risk of fracture in the elderly during the winter months in countries with no accumulation of snow [10,11], with fewer hours of sunshine during the winter and the lack of vitamin D being proposed as contributing causes [17]. As well, as physical performance deteriorates in colder temperatures [23,24], it might also be reasonable to suggest that decreases in physical capacity in cold temperatures increases the risk for falls and, thus, a higher incidence rate of fractures.

Although the risk for fracture for elderly individuals was generally higher in winter, this seasonal pattern was not consistent for all fracture sites. Higher risk of fractures of the forearm other than the distal radius was observed in autumn, though the difference of risk is small. These fractures, such as those of the proximal ulna and proximal radius are high-energy injuries that result from accidents that can occur at any time, independent of temperature or season. By comparison, in children, a more prominent seasonal effect was identified for these fractures, indicating that climate does influence the physical activity patterns of children. Across all age groups, toe fractures were more common in the summer months, with stubbing and crush injuries being

Table 4
Difference in the risk of distal radius fracture by daily weather conditions.

		Age group (years)														
		Children (age 0–19)			Adult (age 20–39)			Adult (age 40–64)			Elderly (age 65–79)			Elderly (age 80+)		
		RR	95% CI		RR	95% CI		RR	95% CI		RR	95% CI		RR	95% CI	
Mean temperature (°C)	< 5	0.64	(0.60, 0.69)	**	2.07	(1.82, 2.35)	**	1.57	(1.47, 1.67)	**	1.45	(1.38, 1.52)	**	1.29	(1.22, 1.38)	**
	5 to 14.9	0.91	(0.88, 0.95)	**	1.69	(1.54, 1.86)	**	1.28	(1.23, 1.34)	**	1.25	(1.21, 1.29)	**	1.21	(1.16, 1.26)	**
	15 to 24.9	1.37	(1.33, 1.42)	**	1.05	(0.95, 1.15)		1.02	(0.98, 1.07)		1.06	(1.02, 1.09)	**	1.07	(1.03, 1.12)	**
	≥25	Reference			Reference			Reference			Reference			Reference		
Difference of temperature (°C)[a]	≤ −2.1	0.92	(0.88, 0.96)	**	0.89	(0.79, 1.00)	*	0.82	(0.78, 0.87)	**	0.85	(0.81, 0.88)	**	0.90	(0.86, 0.95)	**
	−2 to 1.9	0.99	(0.96, 1.02)		0.97	(0.89, 1.05)		0.89	(0.86, 0.93)	**	0.93	(0.90, 0.96)	**	1.00	(0.96, 1.04)	
	≥2.0	Reference			Reference			Reference			Reference			Reference		
Mean wind speed (m/s)	< 3	Reference			Reference			Reference			Reference			Reference		
	≥3	1.06	(1.03, 1.08)	**	1.02	(0.95, 1.08)		1.06	(1.03, 1.09)	**	1.05	(1.03, 1.08)	**	1.02	(0.99, 1.05)	
Rainfall (mm)	< 10	Reference			Reference			Reference			Reference			Reference		
	≥10	0.72	(0.69, 0.75)	**	0.88	(0.79, 0.97)	*	1.02	(0.97, 1.06)		0.89	(0.86, 0.92)	**	0.86	(0.82, 0.90)	**
Total number of cases		28,140			4321			17,648			31,449			22,083		

RR = risk ratio; CI = confidence interval.

* $p < 0.05$.

** $p < 0.01$.

[a] Difference of temperature indicates the difference of daily mean temperature from the previous day.

Table 5
Difference in the risk of hip fracture by weather conditions.

		Age group (years)					
		Elderly (age 65–79)			Elderly (age 80+)		
		RR	95% CI		RR	95% CI	
Mean temperature (°C)	< 5	1.43	(1.35, 1.51)	**	1.32	(1.28, 1.36)	**
	5–14.9	1.40	(1.35, 1.46)	**	1.24	(1.21, 1.26)	**
	15–24.9	1.17	(1.12, 1.21)	**	1.07	(1.05, 1.09)	**
	≥25	Reference			Reference		
Difference of temperature (°C)[a]	≤ −2.1	0.94	(0.89, 0.98)	**	0.94	(0.91, 0.96)	**
	−2 to 1.9	0.95	(0.92, 0.98)	**	1.00	(0.98, 1.02)	
	≥2.0	Reference			Reference		
Mean wind speed (m/s)	< 3	Reference			Reference		
	≥3	1.00	(0.98, 1.03)		1.00	(0.99, 1.02)	
Rainfall (mm)	< 10	Reference			Reference		
	≥10	0.90	(0.86, 0.94)	**	0.93	(0.91, 0.95)	**
Total number of cases		26,035			87,331		

RR = risk ratio; CI = confidence interval.
** $p < 0.01$.
[a] Difference of temperature indicates the difference of daily mean temperature from the previous day.

the principal causes of fracture [25]. The higher risk in summer might reflect the increased likelihood of exposure of toes to environmental factors. As such, wearing shoes might prevent toe fractures.

As part of our analysis, we evaluated the association between daily weather and fracture incidence, which yielded a new finding of an increase in fracture incidence of the distal radius and hip on days with a mean temperature that was warmer than the previous days. This association was independent of the actual daily temperature. Prevention education might target increasing public awareness of the increased risk for fractures not only on colder days, but also on the day following a cold day, even if it gets warmer.

A specific strength of our study is our use of the world's largest health-related database, which included all health insurance claim data in Japan, to identify cases. The advantage of using the NDB for studying disease incidence is the completeness of coverage, with almost all citizens in Japan having public health insurance. Although there are practices not covered by the public health insurance, such as private practice and practice covered by workmen's compensation or automobile insurance, these practices account for only a few percent of all practices. Moreover, the system of medical claim is uniform across multiple insurers, and all claims are recorded in a government-operated standardized fashion. The area of our study had a population of more 40 million people, covering all age groups, from children to elderly individuals. By comparison, a similar study performed using the Medicare claim data in the United States included only the elderly age group [26].

The limitations of our study also need to be acknowledged. The diagnosis recorded on the claim data, which we used for our analysis, might not be as accurate as the diagnosis provided in clinical records. As well, because of the nature of the claim system, hospitals and clinics must justify their claim, leading to a potential loss of specificity of the diagnosis and of an over-diagnosis of fracture. To compensate for this possibility of over-diagnosis, we included only cases in which not only a diagnosis of fracture was declared but also administration of specific treatment for a fracture claimed. This case selection method improved the specificity of the diagnosis of a fracture, with minimal loss of sensitivity. A drawback of this method, however, is the difficulty of application to fracture sites usually treated conservatively and not associated with specific surgical codes. Thus, fractures of vertebrae or pelvis were not included in the analysis. Another limitation is that the time of injury was not recorded on the claim data. Instead, the day of the first visit or admission to hospital due to a fracture, whichever occurred earlier, was assumed to be a proxy for the day of injury. This assumption might cause some error in the time of injury used in the analysis. However, we suggest it would still be a valid proxy for most cases of major fractures because patients are likely to seek medical care immediately, considering the seriously disabling nature of the injury, the absence of geographical barrier in this area, and minimal financial barriers owing to the health insurance coverage. In a study using medical claim data in Taiwan, where a similar insurance system was available, the same assumption was accepted [11]. As patients might watch and wait when they sustained fractures causing less serious symptoms, we limited our analysis for fractures of the hand and foot to seasons and months, rather than day of fracture, to minimize the effect of possible delay in seeking medical care for these fractures. If additional clinical information is included in the database in the future, more precise analysis of the day of injury will be possible. Additionally, the application of our findings for prevention is limited to some degree as the specific cause of seasonal effects remains to be fully clarified. Our findings demonstrate a significant association between fracture incidence and seasons, but not the causative effect of seasons on fracture risk. Biological and well-designed epidemiological studies, controlling for potential confounders, are needed to reveal the causative effect of seasons on fracture incidence. Lastly, recordings from one weather station were considered as representative of the weather of the entire area in our analysis of the association between weather and fracture incidence. The weather the patient actually experienced might be different from the weather recordings we used in this analysis for patients living at a distance from Tokyo. However, areas included in our analysis were geographically adjacent to one another, with an identical terrain and general weather pattern. As well, the population within the area of study tended to be concentrated closer to Tokyo. Therefore, we consider that our use of the weather recordings from the Tokyo District Meteorological Observatory for analysis was reasonable. Future analysis might be conducted using other statistical models, including weather measurement from a location closer to each participant, which would increase the data set and require fewer assumptions.

In spite of these limitations, the findings of our study are important as they add to our knowledge of the epidemiology of fractures, by clarifying the seasonal variation and the effect of weather on the incidence rate of fractures at different sites, in a large population. This knowledge of epidemiology of fractures might make some contributions to patient education to prevent fractures. The elderly and their caregivers should be informed of the increase of risk of fracture in winter season, so that extra caution would be taken. In addition, our findings of significant seasonal effects, which were different for children than for adults and the elderly, have important implications in terms of health policy, including the utilization of medical resources in hospitals and clinics. As the treatment of fractures normally increases the demand on orthopedic service, such as operative theaters, in-patient service, and rehabilitation, knowledge of seasonal effects on fracture risk could improve efficiency in the allocation of services. Knowledge of seasonal variation in fracture incidence could allow resources to be redistributed to other services during off-peak seasonal periods. As an example, scheduling of elective surgery, such as joint replacement in the summer, when elderly patients of fractures are less frequent, might improve the total efficiency of the orthopedic service and subsequent rehabilitation service. Further studies should focus on applying knowledge of seasonal variation for different conditions for the efficient allocation of medical resources.

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References

[1] L.J. Donaldson, I.P. Reckless, S. Scholes, J.S. Mindell, N.J. Shelton, The epidemiology of fractures in England, J. Epidemiol. Community Health 62 (2) (2008) 174–180.
[2] O. Johnell, J.A. Kanis, An estimate of the worldwide prevalence and disability associated with osteoporotic fractures, Osteoporos. Int. 17 (12) (2006) 1726–1733.
[3] T.G. Wadsworth, Colles' fracture, BMJ 301 (6745) (1990) 192–194.
[4] J.D. Zuckerman, Hip fracture, N. Engl. J. Med. 334 (23) (1996) 1519–1525.
[5] M.L. Alvarez-Nebreda, A.B. Jimenez, P. Rodriguez, J.A. Serra, Epidemiology of hip fracture in the elderly in Spain, Bone 42 (2) (2008) 278–285.
[6] J.R. Crawford, M.J. Parker, Seasonal variation of proximal femoral fractures in the United Kingdom, Injury 34 (3) (2003) 223–225.
[7] M. Bulajic-Kopjar, Seasonal variations in incidence of fractures among elderly people, Inj. Prev. 6 (1) (2000) 16–19.
[8] A.R. Levy, D.R. Bensimon, N.E. Mayo, H.G. Leighton, Inclement weather and the risk of hip fracture, Epidemiology 9 (2) (1998) 172–177.
[9] J.M. Tenias, M. Estarlich, E. Crespo, C. Roman-Ortiz, A. Arias-Arias, F. Ballester, Short-term relationship between hip fracture and weather conditions in two Spanish health areas with different climates, J. Environ. Public Health 2015 (2015) 395262.
[10] J.M. Tenias, M. Estarlich, V. Fuentes-Leonarte, C. Iniguez, F. Ballester, Short-term relationship between meteorological variables and hip fractures: an analysis carried out in a health area of the Autonomous Region of Valencia, Spain (1996 – 2005), Bone 45 (4) (2009) 794–798.
[11] H.C. Lin, S. Xiraxagar, Seasonality of hip fractures and estimates of season-attributable effects: a multivariate ARIMA analysis of population-based data, Osteoporos. Int. 17 (6) (2006) 795–806.
[12] S.M. Solbakken, J.H. Magnus, H.E. Meyer, N. Emaus, G.S. Tell, K. Holvik, G. Grimnes, S. Forsmo, B. Schei, A.J. Sogaard, T.K. Omsland, Impact of comorbidity, age, and gender on seasonal variation in hip fracture incidence. A NOREPOS study, Arch. Osteoporos. 9 (2014) 191.
[13] C. Roman Ortiz, J.M. Tenias, M. Estarlich, F. Ballester, Systematic review of the association between climate and hip fractures, Int. J. Biometeorol. 59 (10) (2015) 1511–1522.
[14] M. Hoff, I.A. Torvik, B. Schei, Forearm fractures in Central Norway, 1999 – 2012: incidence, time trends, and seasonal variation, Arch. Osteoporos. 11 (2016) 7.
[15] L. Koren, A. Barak, D. Norman, O. Sachs, E. Peled, Effect of seasonality, weather and holidays on the incidence of proximal hip fracture, Isr. Med. Assoc. J. 16 (5) (2014) 299–302.
[16] A.P. Launonen, V. Lepola, A. Saranko, T. Flinkkila, M. Laitinen, V.M. Mattila, Epidemiology of proximal humerus fractures, Arch. Osteoporos. 10 (2015) 209.
[17] A.B. Gronskag, S. Forsmo, P. Romundstad, A. Langhammer, B. Schei, Incidence and seasonal variation in hip fracture incidence among elderly women in Norway. The HUNT study, Bone 46 (5) (2010) 1294–1298.
[18] N.T. Kubo, T. Myojin, Y. Nishioka, T. Higashino, H. Matsui, G. Kato, T. Imamura, National Database of Health Insurance Claims and Specific Health Checkups of Japan (NDB): Outline and Patient-Matching Technique, bioRxiv, (2018).
[19] Japanese Meteorological Agency, Retrieval system of past weather record, http://www.data.jma.go.jp/obd/stats/etrn/index.php , Accessed date: 15 July 2018.
[20] J.J. Sinikumpu, T. Pokka, H. Hyvonen, R. Ruuhela, W. Serlo, Supracondylar humerus fractures in children: the effect of weather conditions on their risk, Eur. J. Orthop. Surg. Traumatol. 27 (2) (2017) 243–250.
[21] E. Masterson, D. Borton, T. O'Brien, Victims of our climate, Injury 24 (4) (1993) 247–248.
[22] S.J. Jacobsen, D.J. Sargent, E.J. Atkinson, W.M. O'Fallon, L.J. Melton 3rd, Population-based study of the contribution of weather to hip fracture seasonality, Am. J. Epidemiol. 141 (1) (1995) 79–83.
[23] U. Lindemann, J. Oksa, D.A. Skelton, N. Beyer, J. Klenk, J. Zscheile, C. Becker, Effect of cold indoor environment on physical performance of older women living in the community, Age Ageing 43 (4) (2014) 571–575.
[24] J. Oksa, H. Rintamaki, S. Rissanen, Muscle performance and electromyogram activity of the lower leg muscles with different levels of cold exposure, Eur. J. Appl. Physiol. Occup. Physiol. 75 (6) (1997) 484–490.
[25] D. Bica, R.A. Sprouse, J. Armen, Diagnosis and management of common foot fractures, Am. Fam. Physician 93 (3) (2016) 183–191.
[26] H.A. Bischoff-Ferrari, J.E. Orav, J.A. Barrett, J.A. Baron, Effect of seasonality and weather on fracture risk in individuals 65 years and older, Osteoporos. Int. 18 (9) (2007) 1225–1233.