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ORIGINAL ARTICLE

Seasonality of hip fractures and estimates of season-attributable effects: a multivariate ARIMA analysis of population-based data

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Abstract *Introduction:* This study examined seasonal variations in hip fracture rates using nation-wide, population-based data from Taiwan, a subtropical island with fairly uniform weather conditions (mean ambient temperature difference of 11.3°C between peak summer and peak winter months). *Methods:* All inpatients aged 45+ years included in the National Health Insurance Database between 1997 and 2003 and bearing an ICD diagnosis code 820 (fracture neck of femur) were included (n=102,792 cases). *Results:* Auto-regressive integrated moving average (ARIMA) modeling showed significant seasonality and an association of monthly hip fracture admission rates with ambient temperature among both sexes and all three age groups, 45–64, 65–74, and 75+ years. Crude rates show a significant trough during May–August (late spring and summer), followed by a sharp increase in September, and a discernible peak during November–February (late autumn and winter). Adjusted for seasonality, trend, and month, hip fracture rates are significantly reduced among males (b=−0.280, p<0.001) and females (b=−0.341, p<0.001) with increases in the mean ambient temperature. The protective effect of temperature intensifies with age (b=−0.010, −0.241 and −2.263 among the groups aged 45–64, 65–74, and 75+ years, respectively). January (mid-winter) is independently associated with 0.339, 0.663 and 8.153 more hip fractures, respectively, among the three age groups, beyond the temperature effect noted above, and May (late spring) is associated with 0.168, 1.364, and 7.255 fewer fractures. Hours of sunshine and atmospheric pressure were not significant predictors. *Conclusions:* Based on our ARIMA regression coefficients for temperature, January, and May, we estimate that 32.1% of total hip fractures in January (the peak incidence month) are attributable to the season effect among seniors aged 75+ years, 17.2% among those aged 65–74 years, and 11.5% among those aged 45–64 years. We find that in a subtropical climate the effects of winter on hip fracture propensity is significant and increases with age. The policy implications are discussed.

Keywords ARIMA · Hip fracture · Seasonality · Weather

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Introduction

An excessive predisposition to hip fractures among the elderly that is linked to osteoporosis is well-documented. Proximal femoral (hip) fracture is recognized as a major public health problem due to high morbidity, mortality, and health care costs [1], reducing the life expectancy of those affected by as much as 25% [2]. Yet few countries have population-based data on hip fractures, and those that do show a wide range of incidence rates, even within the developed world, suggesting that environmental, diet, lifestyle, and possibly genetic factors influence the basic osteoporotic process and its manifestation as hip fracture morbidity. For example, among French women, the annual hip fracture rate is 440 per 100,000 among those aged 50+ years; this figure is 579 among their Japanese counterparts, and 859 among their Swedish counterparts [3]. Male to female ratios are also variable, as documented by many authors, such as Maggi et al. [4]. Worldwide, women face an estimated lifetime hip fracture risk of 40% compared to 13% for men [3, 4]. In the U.S. alone, more than 250,000 cases of hip fractures occur every year [5], with the associated lifetime costs exceeding US $20 billion in 1997 [2].

As the developing world's population ages, the incidence of hip fractures worldwide are expected to increase from 1.26 million in 1990 to 2.6 million by the year 2025 and to 4.5 million by the year 2050 [6]. Most developed countries already have high proportions of an elderly population, with about 15% of their combined 1.2 billion inhabitants aged 65+ years in 2003 [7]. This increasing aging trend shown by the populations of developing countries may be associated with a higher rate of osteoporotic fractures than in the Western countries [3], possibly due to lower bone mass accretion in their growing years due to nutritional deficiencies [8]. About 5 billion of the world's 6.2 billion population lives in the developing world, mainly the equatorial, tropical, and sub-tropical regions. Thus, the identification of the risk factors for hip fractures, including seasonality, in the tropics and subtropics is critical to the development of effective preventive programs against osteoporosis and also of logistics needed by countries in order to plan ahead for health resources based on seasonal expectancies.

Seasonality in hip fracture incidence

The important role of vitamin D synthesis in the skin following exposure to sunshine and its seasonal variation in temperate countries is well documented. Bhattoa et al. showed that Hungarian post-menopausal women had (age and diet adjusted) hypovitaminosis D prevalence rates of 71%, 46.3%, 49.4% and 56.7% in spring, summer, autumn and winter, respectively, with the prevalence significantly associated with average number of hours of sunshine daily in the 3 months prior to testing [9]. Kim and Moon demonstrated seasonal variations in serum vitamin D levels among Korean women, along with positive correlations with hours of sunlight exposure adjusted for dietary vitamin D [10].

The association of serum 25-hydoxycholecalciferol (OHC, a vitamin D metabolite) with bone density is also well documented. For example, Muenier reported a significant negative correlation between OHC levels and parathyroid hormone levels as well as bone density among the elderly, followed by restoration of bone density and a reduction of parathormone levels following dietary supplementation with vitamin D and calcium [11]. Apart from vitamin D's impact on bone density, it has also been found to improve muscle strength and coordination among the elderly, both key factors in functional mobility and resistance to falls [12]. These neuro-muscular effects are thought to contribute to reduced hip fracture rates by preventing or reducing the number of fracture-relevant falls among the elderly. Negative correlations between serum OHC levels and rate of falls as well as objective measures of functional mobility have also been found [13]. Collectively, these findings suggest that winter may be associated with increasing hip fractures due to a reduced exposure to sunshine.

The evidence on hip fracture seasonality, however, has not been unequivocal, with studies from the U.S., Canada, UK, Sweden, Australia, Spain, Italy, Hong Kong, and South Korea [14–26] showing variable results: an increase in the winter months [14, 15], an increase in the summer months [26], and no seasonal variation at all [16, 18, 23]. Past incidence studies have relied on data from a few selected hospitals or sub-groups of populations which may account for inconsistencies across studies. Many studies had inadequate statistical power to detect any difference due to limitations in the data sources, such as a single hospital's admissions or a single district's admissions.

An important lacuna in the literature is that almost all seasonality studies to date have been conducted in temperate (high latitude) countries, many focusing on severe weather conditions such snow, ice, and freezing rain. A notable exception is the study of Douglas et al. who examined seasonal variation of hip fracture rates among a panel of patients of a team of surgeons who operated at hospitals located at three latitudes, Scotland (northern hemisphere), New Zealand (southern hemisphere), and Hong Kong (northern hemisphere tropics) [24]. At all three latitudes, the consistent association between incidence of hip fractures and the winter months was noted. Although this was the first study that documented the significance of winter in a tropical climate, its utility is limited, being based on one surgical group's panel of patients.

Finally, the documented seasonality studies are methodologically limited by univariate statistical analysis. Few studies have examined the association of hip fracture rates with meteorological factors. Only one study has examined crude correlations (also a univariate method) with ambient temperature, relative humidity, atmospheric pressure, rainfall, and hours of sunshine [15]. Given the high correlations between meteorological parameters in each season, univariate analysis is inadequate to identify the significant contributing factors, thereby hampering policy initiatives to reduce hip fractures.

Study setting

This study addresses some gaps in our understanding of hip fracture incidence, particularly in warmer climates, and addresses some of the methodological weaknesses of earlier studies. In this report we examine nation-wide, population-based data collected on inpatients during an 84-month time window using multivariate time series analysis to explore seasonal and meteorological factors in hip fracture incidence. Taiwan, being an island state, has an extremely low immigration rate, and a homogeneous population (98% Han Chinese). Thus, it presents an opportunity to study a stable population over a 7-year study period, precluding confounding by different rates in diverse ethnic and immigrant populations.

Inpatient claims data from Taiwan's National Health Insurance (NHI) program was used. NHI is a single payer system and has covered all 23 million-plus citizens with a comprehensive benefit package and low co-payments since

1995. Its research database is plausibly the largest and most comprehensive population-based database in the world, providing a (ICD-9-CM) primary diagnosis and up to four secondary diagnoses.

Methods

Study sample

Our study population consisted of all inpatient claims for hip fracture (ICD code 820 as the primary or secondary diagnosis) in Taiwan between 1997 and 2003 – a total of 102,385 cases after excluding patients younger than 45 years (n=12,678; likely to be mostly traumatic), readmissions (n=16,904), and pathological fractures (n= 407). Study patients were classified by gender and by age: 45–64, 65–74, and ≥75 years. The mean age was 75.4 years (SD: 10.5 years), and the female to male ratio was 1.39.

We assume the date of admission as the date of sustaining the fracture, since the latter is not available in the NHIRD. Given universal health care coverage, negligible financial access barriers, and the seriously disabling nature of femoral neck fractures, we believe our assumption to be valid.

Hip fracture rate calculation

Mid-year population data, released annually by the Population Affairs Administration of the Ministry of the Interior, in each age and gender group served as denominators to calculate age- and gender-specific incidence rates per 100,000 persons. The number of fractures that occurred in each month was standardized to a 30-day period to compensate for unequal lengths of the calendar months.

Although an estimated 20% of hip fractures among the elderly are thought to be fatal, we did not include data from cause of death statistics. Cause of death statistics may not be reliable when a patient is brought dead to the hospital because the physician has not had a chance to evaluate the live patient for fracture, and clinical autopsy is not routine procedure in Taiwan. As such, especially in elderly patients, death may be attributed to a variety of causes, depending on the antecedent diagnoses (such as myocardial infarction, cardiac arrest, acute cerebro-vascular accident, etc.). If a patient died in the emergency room after arrival, an inpatient claim is logged in, and this patient would therefore be included in our study sample.

Meteorological data and season definitions

Meteorological data on number of hours of sunshine daily, ambient temperature, minimum and maximum temperature, relative humidity, atmospheric pressure, and rainfall from 19 weather bureau observatories were averaged to obtain monthly data for the whole of Taiwan. (Data from seven stations located in the sparsely populated mountainous regions were ignored). Since Taiwan is a small island, covering 36,188 square kilometers, with human habitation limited to the rim bordering the coast, a single monthly mean meteorological value was judged to be appropriate for the entire island.

Located between latitudes 2145′N and 2556′N, Taiwan's weather is sub-tropical, being warm and humid throughout the year, without any gross season variation in weather conditions. During the study period, the monthly mean (24-h) ambient temperature was the highest in July, the peak summer month, at 28.3°C, and the lowest in January, the peak winter month, at 17.0°C. The Central Weather Bureau (CWB) defines spring as March–May, summer as June–August, autumn as September–November, and winter as December–February.

Statistical analysis

Monthly hip fracture rates per 100,000 persons were calculated across the 7-year study period. Because seasonality is a general component of the time series pattern, the data were evaluated for seasonality by the 'auto-regressive integrated moving average' (ARIMA) regression method. This technique defines a univariate time series as a function of its past values and other significant independent variables and has been used in many analogous studies to test for seasonality and environmental effects. The ARIMA model uses autoregressive parameters, moving average parameters, and the number of differencing passes to define the series in which a pattern is repeated seasonally over time (for example, to examine for and average out across annual trends, expecting monthly values to be correlated, the number of differencing passes would be programmed as 12, 24, 36).

To examine associations between climate factors and hip fracture incidence, crude correlations were computed, followed by ARIMA regression modeling to evaluate the effects of climate and month, controlling for time-trend effects. Months were included in the model in the form of a series of dummy variables, running from January to December, with a specific month given a value of 1, while the remaining months were given a value of 0. Climate data included daily hours of sunshine, ambient temperature, minimum temperature, maximum temperature, relative humidity, atmospheric pressure, and rainfall.

The time trend was a count variable numbered from 1 to 84 according to the time series. To model the data using the most parsimonious model, we included only statistically significant independent variables in the final ARIMA regression models (presented in the Results section). Selection of the final model was based upon the lowest mean absolute percentage error, or mean absolute error, thereby allowing the choice of the best model from the family of models. All p values of <0.05 were considered to be statistically significant in this study.

Results

Hip fracture incidence rates

Between 1997 and 2003, the mean monthly hip fracture admission rate in Taiwan among the population aged 45+ years was 19.2 per 100,000 (Table 1), or an annual rate of 230.4 per 100,000. There were 13,404 admissions in 1997, 13,635 in 1998, 14,310 in 1999, 14,600 in 2000, 15,113 in 2001, 15,520 in the year 2002, and 15,803 in 2003, with the respective annual rates (per 100,000 of the population) being 241.5, 236.0, 240.0, 235.3, 234.3, 232.5, and 226.9.

Table 1 shows that the mean monthly incidence of hip fracture admissions in Taiwan for the 45+ age group was 22.7 among females and 15.9 among females. Among females, the respective mean monthly rates for the 45–64, 65–74, and 75+ age groups were 3.6, 30.5 and 135.7; among males, the respective mean rates by age groups were 4.6, 21.5 and 77.0. The highest mean monthly ambient temperature during the study period was in July – 28.3°C – and the lowest was in January – 17°C. Average hip fracture rates (per 100,000) for January across the 7-year period among the 45–64, 65–74, and 75+ age groups were 4.4, 27.4 and 127.6, respectively; for July, the corresponding rates were, 3.9, 23.2, and 92.6, respectively (not shown on Table).

Table 2 summarizes the profile of the sampled cases. Of the 102,385 hip fractures, 58.1% were female, and 59.3% were older than 75 years. The majority of study patients were diagnosed with fracture of the inter-trochanteric section of femur, closed (ICD-9-CM, code 82021) (40.2%) and fracture of an unspecified part of the neck of the femur, closed (ICD-9-CM, code 8208) (38.3%). A total of 1023 (1%) cases of in-hospital mortality were registered.

Seasonal variations

Seasonal variations in monthly hip fracture admissions for males and females and by age group (45~64, 65~74 and >74 years), gender-wise as well as pooled, are illustrated in Fig. 1. A generally similar seasonal pattern in hip fracture rates across gender and age groups is observed. Seasonal trends show a significant trough in May–August (late spring and summer), followed by a sharp increase in September, and a discernible peak during November–February (late autumn and winter). Similar seasonal trends are observed among the age groups. High rates are observed in November–February, a decline in March, and a trough during May–July.

Climatic influence

Across the 7-year study period, the mean ambient temperature was 23.2°C, the mean relative humidity was 78.2%,

Table 1 Monthly mean hip fracture admissions and meteorological conditions in Taiwan between 1997 and 2003 (*n* = all 102,385 hip fracture admissions, excluding re-admissions)

Variable	Monthly mean	Standard deviation	Minimum	Maximum
Hip fractures/100,000 persons aged 45+ years	19.2	1.9	14.8	23.3
Hip fractures/00,000 males aged 45+ years	15.9	1.7	12.5	19.7
Hip fractures/100,000 females aged 45+ years	22.7	2.3	17.1	27.8
Hip fractures/100,000 persons aged 45–64 years				
Total	4.0	0.4	3.3	5.6
Male	4.6	0.6	3.5	6.3
Female	3.6	0.5	2.7	5.3
Hip fractures/100,000 persons aged 65–74 years				
Total	25.4	2.4	20.0	31.3
Male	21.5	2.7	16.3	27.4
Female	30.5	3.2	24.1	40.6
Hip fractures/100,000 persons aged 75+ years				
Total	104.2	13.7	70.5	136.5
Male	77.0	11.1	55.6	107.8
Female	135.7	17.0	91.7	178.8
Ambient temperature (°C)[a]	23.2	4.0	16.2	29.3
Relative humidity (%)	78.2	2.8	70.3	83.7
Atmospheric pressure (hPa)	999.6	4.9	990.7	1007.9
Rainfall (mm)	173.9	85.3	28.8	527.0
Sunshine (hours)	158.2	119.2	20.8	889.8
Maximum temperature (°C)	26.8	4.1	19.0	33.2
Minimum temperature (°C)	20.5	4.0	13.2	26.4

[a]Ambient temperature is the mean of 24-h daily temperatures averaged over each month. The mean shown here is the mean of all 12 months over the 7-year study period

Table 2 Demographic and fracture site distribution among hip fracture inpatients aged 45+ years in Taiwan, 1997–2003 (*n*=all 102,385, excludes re-admissions and pathological fractures)

Variable	*n* (%)
Gender	
Male	42,891 (41.9)
Female	59,494 (58.1)
Age group (years)	
45~64	14,849 (14.5)
65~74	26,813 (26.2)
≥75	60,723 (59.3)
Diagnosis (ICD-9-CM)	
Fracture of neck of femur (820)	354 (0.3)
Transcervical fracture of femur, closed (8200)	344 (0.3)
Transcervical fracture of femur, open (8201)	84 (0.1)
Pertrochanteric fracture of femur, closed (8202)	310 (0.3)
Pertrochanteric fracture of femur, open (8203)	28 (0.0)
Fracture of unspecified part of neck of femur, closed (8208)	39,386 (38.3)
Fracture of unspecified part of neck of femur, open (8209)	257 (0.30
Unspecified fracture of intracapsular section of femur, closed (82000)	1,614 (1.6)
Fracture of epiphysis (separation) (upper)of femur, closed (82001)	631 (0.6)
Fracture of midcervical section of femur, closed (82002)	2,215 (2.2)
Fracture of base of neck of femur, closed (82003)	2,782 (2.7)
Other fracture of neck of femur, closed (82009)	5,416 (5.3)
Unspecified fracture of intracapsular section of femur, open (82010)	43 (0.0)
Fracture of epiphysis (separation) (upper)of femur, open (82011)	37 (0.0)
Fracture of midcervical section of femur, open (82012)	103 (0.1)
Fracture of base of neck of femur, open (82013)	66 (0.1)
Other fracture of neck of femur, open (82019)	69 (0.1)
Unspecified fracture of trochanteric section of femur, closed (82020)	3,828 (3.7)
Fracture of intertrochanteric section of femur, closed (82021)	41,289 (40.2)
Fracture of subtrochanteric section of femur, closed (82022)	3,567 (3.5)
Unspecified fracture of trochanteric section of femur, open (82030)	42 (0.0)
Fracture of intertrochanteric section of femur, open (82031)	245 (0.2)
Fracture of subtrochanteric section of femur, open (82032)	82 (0.1)
Length of hospital stay (days)	11.4 (mean)
Total costs (NT$)	73,763 (mean)
Inpatient mortality	1,023 (1%)

the mean atmospheric pressure was 999.62 hPa, mean rainfall was 173.9 mm, and mean hours of sunshine daily was 158.2 (Table 1). Bivariate associations between monthly meteorological parameters and hip fracture admission rates, by gender and age, are graphically illustrated in Fig. 2.

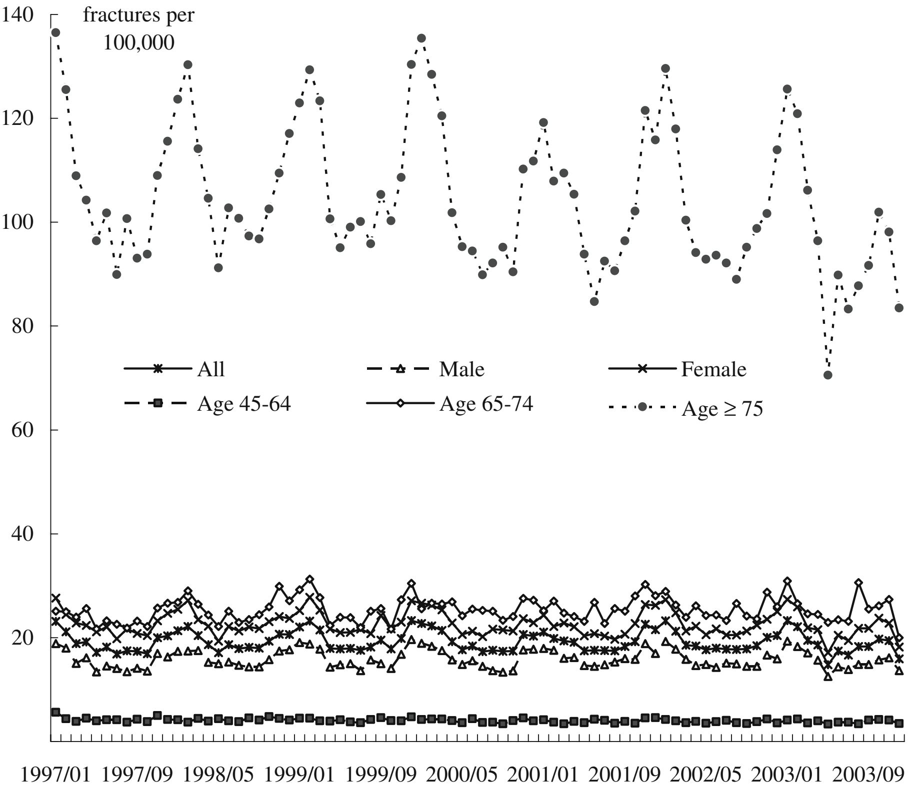
Table 3 shows the cross-correlation coefficients between climatic factors and hip fracture. Significant negative associations are found with ambient temperature among both genders and all age groups (all $p<0.001$). Positive associations are observed between atmospheric pressure and hip fractures in both genders and all age groups (all $p<0.001$). The number of hours of sunshine shows negative associations for both genders and all age groups except for the group aged 45–64 years. Relative humidity is not visibly associated with hip fracture rates.

ARIMA regression findings

The ARIMA test for seasonality in hip fracture admission rates was found to be significant for each gender and for each age group [$p<0.05$ for all seasonal autoregressive terms (SAR)] (not shown on Table). The most appropriate model for the ARIMA test was a multiplicative model with trend and seasonality parameters of (1,0,0) and (3,0,0), respectively. The (1,0,0) (3,0,0) model incorporates one autoregressive parameter, no moving average parameters, three SAR parameters, and no seasonal moving average parameters. These parameters were computed for the series without any differencing (such as seasonal differencing).

Table 4 shows the adjusted associations of specific months and climatic factors with hip fracture admission, controlling for seasonality and trend using ARIMA

Fig. 1 Monthly admissions for hip fracture in Taiwan per 100,000 persons from 1999 to 2003



regression analysis. Some differences in monthly factors are observed by gender and age groups. Among males, hip fracture rates tended to be higher in January (mid winter) and November (late fall, all $p<0.01$) and lower in May (late spring, $p<0.05$) compared to other months throughout the 7-year study period. Among females, in addition to the above features observed among males, higher hip fracture rates continued through February (late winter, $p<0.05$). The R^2 values for the ARIMA regression models for male and female rates were as high as 0.764 and 0.726, respectively.

When examined by age group, we observe similar increases in January and November and the dip in May among all age groups, except for the 65–74 age group, which shows an insignificant effect of the month of January. Other exceptions is the lack of effect of the month of November among the 75+ age group and the significant increase in August among the 65–74 age group.

Finally, after adjustment for seasonality, trend, and month, the hip fracture rates are significantly affected by mean ambient temperature among males (b=−0.280, $p<0.001$) and females (b=−0.341, $p<0.001$). Classified by age, hip fractures among the age groups 65–74 and ≥ 75 years show a significant association with mean ambient temperature (b=−0.241, $p<0.01$; b=−2.263, $p<0.001$, respectively), but this association is not observed among the 45–64 age group (b=−0.010; $p>0.05$). Number of hours of sunshine and atmospheric pressure were no longer statistically significant after accounting for mean ambient temperature, month, seasonality, and time trend.

Estimation of season-attributable mid-winter effect

The mean temperature during January over the 7-year period was 17.0°C; during July, it was 28.3°C (the month with the highest average temperature), a mean difference of 11.3°C. The maximum hip fracture rate among the 75+ age group is in mid winter (January). We estimated the season-attributable effect on January hip fracture rates by using the ARIMA model coefficient for temperature, and the coefficients for January and May in each age group. Among the 75+ age group, the season-attributable change in January is 40.94 cases relative to July. This is computed by the sum of the ARIMA regression coefficient for January of 8.153, the estimate for May of 7.255, and the temperature effect of 15.408, which is the ARIMA coefficient for temperature of 2.263 × 11.3, the latter being the difference in temperatures of the highest and lowest temperature months. Since the steep hip fracture decline in May is statistically determined to be equal on average with that of the summer months (because summer months were not significant in the regression), the estimate for May is used to represent the "summer month" effect, adjusted for the temperature effect. Thus, of the total January hip fractures among the 75+ age group, 32.1% (40.94/127.6) may be attributable to the January effect relative to July. The comparable season-attributable effect among the 65–74 age group is 4.74 cases or 17.2% (4.74/27.4) of the total January cases. The season-attributable effect is 0.507 cases among the 45–64 age group, or 11.5% of the total January cases.

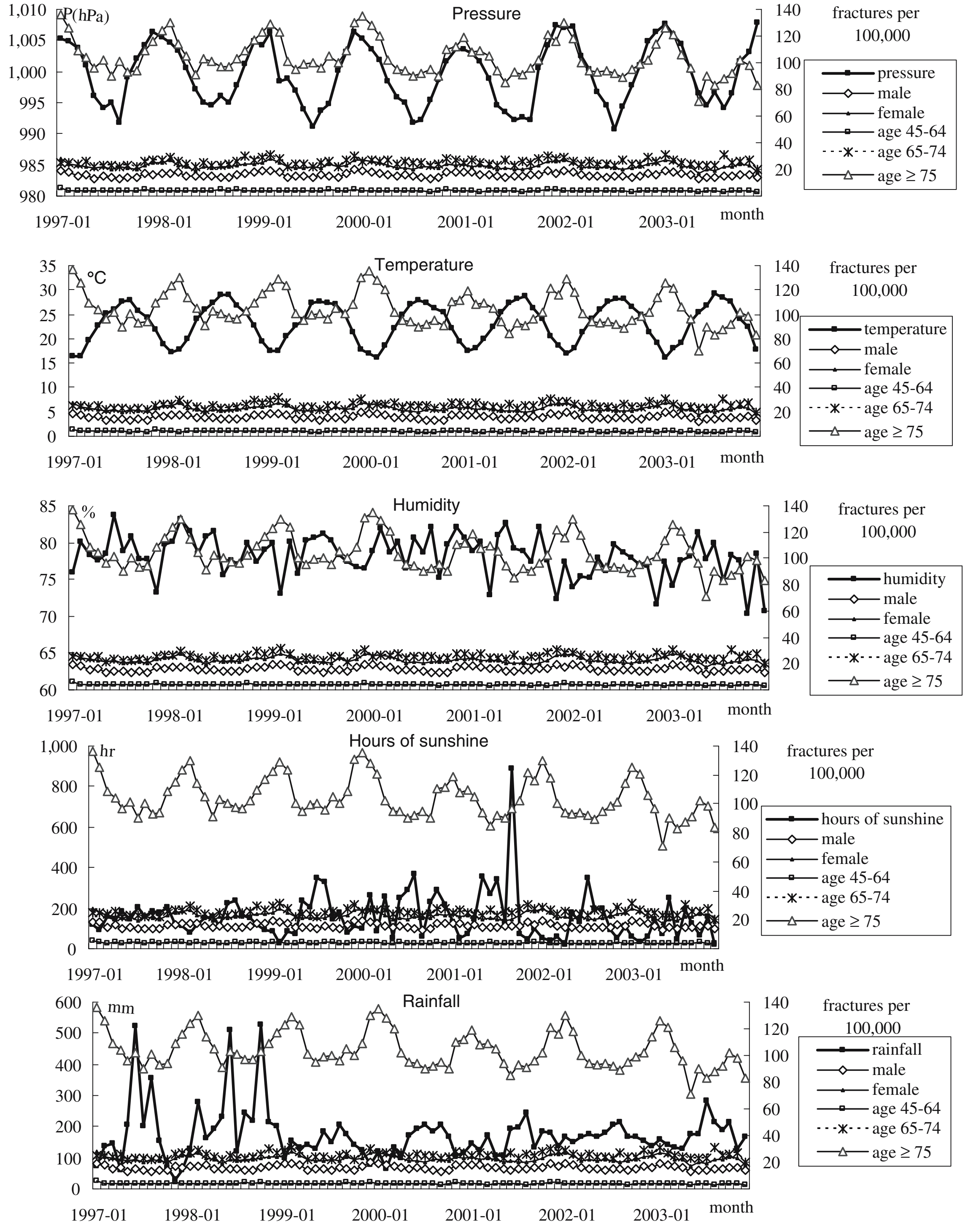


Fig. 2 Plots of monthly hip fracture rates versus meteorological levels in Taiwan, 1997–2003

Discussion

This study represents a rare opportunity to conduct a 7-year study on the incidence, seasonality, and climatic factors affecting hip fracture rates using a national population-based health care database. The annual hip fracture admission rates for females and males are 1628 and 924, respectively among the elderly of Taiwan over 75 years of age, with a female to male ratio of 1.44. The ratio in Taiwan is significantly lower than that found in most European countries: for example Belgium has a female to male ratio of 2.3:1 and France, 2.6:1 [27]. Taiwan's hip fracture admission rate is nearly half that for French women – 440 per 100,000 – and lower than that among Japanese women (579 per 100,000) and Swedish women (859 per 100,000).

Table 3 Crude correlations between climate factors and monthly hip fracture rates in Taiwan, 1997–2003

Hip fractures/per 100,000 population	Temperature	Relative humidity	Rainfall	Sunshine hours	Pressure
Total	−0.810***	−0.121	−0.270*	−0.322**	0.730***
Male	−0.810***	−0.095	−0.309**	−0.267*	0.712***
Female	−0.756***	−0.126	−0.218*	−0.341***	0.692***
Age 45–64	−0.337**	−0.039	−0.109	−0.036	0.341***
Age 65–74	−0.486***	−0.128	−0.146	−0.235*	0.479***
Age ≥75	−0.830***	−0.420	−0.264*	−0.312**	0.711***

*$p<0.05$;**$p<0.01$;***$p<0.001$

A portion of these differences may be due to differences in the age composition of the national population.

We find consistent seasonal patterns in hip fracture admissions among a homogenous ethnic Chinese population (98% of Taiwan's population is Chinese), aged 45 years or more, among both sexes, and among all age groups. We find a significant dip in hip fracture rates in the early spring, followed by a trough to the lowest rate in May which continues in the summer months, a significant increase in November (autumn), and a peaking to the highest rate in January. Our findings are consistent with the winter peaks reported by Jacobsen et al. [14], Mirchandani et al. [15] and Chesser et al. [16]. Two studies have reported findings that contradict our study: both found peak hip fractures during the summer among the elderly in South Korea [26] and in Spain [27]. Both studies, however, were based on very small sample sizes of 405 and 301 cases, respectively, which raises the issue of sampling bias, suggesting that the studies are likely to be statistically inadequate to examine seasonality.

Except for a study in Hong Kong, all previous studies on an association between hip fracture incidence and season have been reported from temperate or Scandinavian climates where the intensity and number of hours of sunshine are very low during the winter. The study from Hong Kong is the only study from a sun-belt setting. Our study, drawing from population-based data in a sub-tropical setting, validates earlier findings from temperate countries that were based on data from a city, district, or group of hospitals.

An important contribution of this study is that it confirms the significant role of the summer-winter seasonal difference in hip fractures, even in a sub-tropical climate which has quite a significant number of hours of sunshine daily during the winter months and no drastic difference in ambient temperatures between summer and winter – only 11.3°C. A similar seasonality has been documented by only one other study in Hong Kong, which examined a panel of patients treated by a team of orthopedic surgeons [25]. Earlier studies in the sub-tropics have been limited to in vitro studies of vitamin D synthesis (considered a standardized proxy for in vivo synthesis) following exposure to sunshine during each month of the year at different latitudes. For example, Pettifor et al. found that Johannesburg in South Africa (a lower, more tropical latitude) showed little seasonal variation in in-vitro vitamin D synthesis, whereas Cape Town, which is located at a higher latitude, showed a much reduced synthesis during the winter months [28]. These researchers attributed reduced in vivo vitamin D levels in the winter at Johannesburg to increased clothing and reduced outdoor time during the winter rather than to a decreased amount of sunshine reaching the earth. In contrast, Ladizesky et al. reported seasonal variation of in vitro vitamin D synthesis in the sub-tropical city of Buenos Aires (34°S), with the lowest rate in winter, followed, in decreasing order, by spring, autumn and summer [29]. They also reported significantly lower rates at Ushuaia (55°S) in all seasons, with very low synthesis rates in the winter months. Our study presents a population-based clinical snapshot of the outcome of the sunshine exposure-vitamin D connection among the elderly living on a sub-tropical island.

We find that monthly temperature rather than number of hours of sunshine is statistically significant, and once monthly temperature is accounted for, number of hours of sunshine is insignificant. Monthly average temperatures are more indicative of the intensity of sunshine and possibly represent a consistent proxy for a higher average UV index in summer. This is likely because number of hours of sunshine is less variable between the summer and winter in the tropics and sub-tropics (compared to the variation in cold countries). Therefore, average monthly temperature appears to serve as a proxy for sunshine intensity, in turn for the season, which may be more predictive of bone density variations, keeping in view the role of sunshine in Vitamin D synthesis.

From the clinical pathology perspective, our data indicate an increasing role of season with increasing age and with osteoporosis levels. Among the group aged 45–64 years, monthly temperature has a statistically insignificant effect on hip fracture rates, once month is accounted for: January (mid-winter) shows an excess of 0.34 fractures per 100,000 over the average month (excluding the specific months included in the model), and May (late spring) shows 2.11 fewer fractures per 100,000. Among the group aged 65–74 years, increasing monthly temperature has a protective effect, reducing monthly hip fracture rates by 0.24 per 100,000 for every degree Celsius increase in temperature, with an additional 0.66 fractures per 100,000 in January and a 1.36 reduction in fractures in May. Among 75+ age group, the protective effect of increasing temperature is much more marked, a reduction of 2.26 fractures per 100,000 per month for every degree Celsius increase in ambient temperature. Additionally, January shows an

Table 4 ARIMA regression analysis showing seasonality and meteorological effects on monthly hip fracture rates in Taiwan (n=102,385)

Independent variable[a]	Male			Female			Age 45–64 years			Age 65–74 years			Age ≧75 years		
	β	SE	*t*-value	β	SE	*t*-value	β	SE	*t*-value	β	SE	*t*-value	β	SE	*t*-value
Intercept	22.168	0.959	23.11***	30.968	1.016	30.48***	4.510	0.193	23.33***	29.990	2.026	14.80***	162.115	5.458	29.70***
AR1	0.334	0.131	2.56*	0.235	0.139	1.69	−0.210	0.120	−1.75	0.227	0.133	1.71	0.235	0.143	1.65
SAR12	0.054	0.139	0.38	−0.150	0.158	−0.95	−0.227	0.114	−1.98	0.074	0.154	0.48	−0.055	0.161	−0.34
SAR24	−0.107	0.140	−0.76	−0.344	0.151	−2.27*	−0.220	0.118	−1.87	−0.104	0.160	−0.65	−0.271	0.150	−1.81
SAR36	−0.135	0.153	−0.89	−0.084	0.179	−0.47	−0.364	0.129	−2.81**	−0.062	0.178	−0.35	−0.011	0.177	−0.06
Mean temperature	−0.280	0.039	−7.24***	−0.341	0.041	−8.28***	−0.010	0.008	−1.34	−0.241	0.082	−2.93**	−2.263	0.223	−10.15***
January	1.143	0.393	2.91**	1.256	0.441	2.84**	0.339	0.102	3.33**	0.663	0.922	0.72	8.153	2.365	3.45***
February	0.710	0.371	1.91	0.962	0.416	2.31*	0.019	0.097	0.20	1.100	0.834	1.32	5.203	2.262	2.30*
May	−0.750	0.300	−2.50*	−1.681	0.344	−4.89***	−0.168	0.080	−2.11*	−1.364	0.683	−2.00*	−7.255	1.894	−3.83***
August	0.345	0.305	1.13	0.220	0.355	0.62	−0.118	0.090	−1.32	1.737	0.743	2.34*	0.637	1.926	0.33
November	1.357	0.301	4.51***	0.803	0.344	2.34*	0.476	0.084	5.66***	2.646	0.694	3.81***	2.849	1.880	1.52
Trend	−0.002	0.006	−0.26	−0.013	0.007	−1.90	−0.007	0.001	−6.79***	0.014	0.012	1.21	−0.145	0.034	−4.27***
MAPE			4.1013			3.9920			5.4516			5.2986			4.1606
MAE			0.6325			0.8970			0.2219			1.3423			4.2338
R^2			0.764			0.726			0.466			0.462			0.827

*p<0.05, **p<0.01, ***p<0.001

[a] AR1: Autoregressive, Lag 1; SAR12 (24, 36): seasonal autoregressive, Lag 12 (24, 36); MAPE: mean absolute percent error; MAE: mean absolute error; ambient temperature is the monthly mean of average daily (24-h) temperature

increase of 8.15 hip fractures per 100,000, and May shows 7.25 fewer fractures. The steep age-related increase in winter fractures among the older elderly may reflect two factors. One is that with increasing age, the elderly have increasingly higher vitamin D requirements to sustain bone density due to increasing parathyroid activity ushered in with diminishing renal function [30]. Second, age is documented to decrease the capacity of human skin to produce vitamin D [31].

If the specific month effects are attributed to the vitamin D-mediated effect of sunlight on bone density and functional mobility, then the differences in hip fracture incidence between the highest and lowest temperature months would represent a measure of the protective effect of summer sunshine. The season-attributable effect, estimated based on the ARIMA seasonality and ambient temperature coefficients, accounts for 32.1% of the January hip fracture rate among the 75+ age group compared to 17.2% of the January rate among the 64–75 age group and 11.5% among the 45–64 age group.

The data suggest that the intensity of the winter sunshine is inadequate for the older age groups, even in sub-tropical regions. Alternatively, our findings may be reflecting a reduced duration of actual exposure experienced by persons of different age groups as a result of differences in age-related activities. In the 45–64 (working) age group, routine commuting to and from work, outdoor work if applicable, and chores result in some degree of exposure. Our data show an increase in winter-linked fracture propensity among the 65–74 age group, and steep increases in fracture propensity among the 75–84 age group. The older elderly are much less likely to be engaged in an active life style than the younger elderly, more so in the winter, when they may be discouraged by colder temperatures from participating in outdoor activities. Further, in joint families, their involvement in daily outdoor chores and activities tends to be optional, and the older elderly just may avoid them. This may explain the steadily increasing trend in hip fractures with increasing age. Other factors have also been postulated, such as reduced dexterity in winter due to decreased body temperature [15, 32, 33] and decreasing physical activity in cold weather among the elderly, resulting in impaired conditioning and subsequent bone fragility [34].

Our study also finds a significant increase in hip fractures in November among the 45–64 and 65–74 age-groups. November represents the end of the fall, with significantly diminished sunshine compared to summer. The hip fracture surge in November among these two age groups, but not in the 75-plus group, plausibly represents the interaction of a vacation season effect with climatic season effect. November is the peak vacation month in Taiwan. Government employees as well as other employees typically accrue vacation time, and this cannot be accumulated beyond a point and has to be expended by the end of the calendar year. Weather conditions are also pleasant in November and, consequently, maximum vacation travel takes place. According to the Tourism Bureau statistics of the Ministry of Transportation and Communications, between 2001 and 2003 November can be associated with the highest hotel occupancy rate (about 70%) among all months [35]. Due to the preponderance of the joint family system in Taiwan, families taking travel vacations frequently take their elderly parents with them. Issues involving physical and ambulatory adaptation to unfamiliar places and activity levels beyond those of the usual routine are plausible causal factors for the November hip fracture peak in the 45–64 and 65–74 age groups. No such surge is noted in the older elderly; typically, this age group travels far less, either due to adaptability issues in unfamiliar surroundings, or health problems (existing or anticipated) associated with travel.

The August surge in hip fractures among the 65–74 age group probably reflects an increased risk due to tourism, as August is another preferred travel month. School children prepare to return to school in September after their summer vacations, and August is the most pleasant among the summer months for travel due to declining heat and humidity conditions. Again, in joint families, grandparents typically are included in family vacations, and (the younger) healthy elderly frequently take grandchildren on educational vacations on their own. Our hip fracture data showing a very significant spike in November among the two younger age groups and an August spike among the 65–74 age group is in agreement with local cultural preferences.

Future research and policy implications

Our findings on hip fractures are of considerable clinical and policy interest, given that the data are population-based, have ample statistical power, and yield detailed information on seasonality that is based on sophisticated statistical techniques to overcome collinearity, confounding, and serial auto-correlation. We are also able to compute realistic measures of season-attributable effects. Being the only large-scale, population-based study that has been conducted in the sub-tropics to date, it has an international policy significance within the context of addressing an important cause of morbidity in an increasingly aging global population in developing countries.

Sharp winter-summer differences call for policies to facilitate the widespread adoption of vitamin D and calcium supplementation among the elderly. A positive impact of dietary vitamin D and calcium supplementation on bone density and functional ability is documented [9, 11, 13]. Additional approaches could be to explore the possibility of modulated ultraviolet lamp exposure of the elderly in winter in order to compensate for potential malabsorption and other systemic geriatric issues interfering with the absorption of dietary vitamin D. Although the beneficial effect of artificial ultraviolet exposure on serum vitamin D levels and bone mineral density is well documented [36, 37], more studies are needed to examine its utility among the elderly, particularly in the light of studies showing that vitamin D synthesis in response to ultraviolet light may be compromised due to skin changes among the elderly [31]. Based on the findings, a useful policy initiative may be to cover ultraviolet exposure sessions for the elderly during winter as a health insurance benefit.

Another major policy implication is the ensuring of an adequate availability of health infrastructure and specialized personnel, including orthopedic surgeons, to deal with increased hip fracture rates during the winter. With limited orthopedic surgeon availability, elective procedures should be scheduled in other seasons to accommodate the need for increased services for this population during the late autumn and winter months.

Study limitations

A major limitation of the study is that the data are drawn from the NHI's inpatient medical benefit claims. Hip fracture incidence is necessarily underestimated because a proportion of patients may be brought dead to the hospital or may die at home due to lack of recognition of the seriousness of the reduced mobility in an already compromised patient. As indicated earlier, cause of death statistics may not be reliable for deaths occurring outside the hospital.

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