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REVIEW PAPER

Systematic review of the association between climate and hip fractures

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Abstract This study aims to systematically review epidemiological studies that evaluate the relationship between meteorology and the incidence of hip fracture (HF). After a search in Scopus, PubMed, and Embase, two independent authors assessed the relevance of studies and extracted data for description. From each study, we extracted the geographic and temporal scope, design, study variables (meteorological and related to HF), statistical analysis, and estimated associations. Of a total of 134 works, 20 studies were selected. All use an ecological design but one case-crossover. Most studies have been conducted in northern latitudes. The analysis methodology did not take into account the temporal structure of the data in 10 studies (regression and linear correlations); the rest used Poisson regression (7) and ARIMA model (3). Most studies showed significant positive associations with rainfall, especially in the form of snow: HF relative risk (RR) on days with precipitation vs. days without precipitation that ranged from 1.14 (95 % confidence interval (CI)1.04 to 1.24) to 1.60 (95 % CI 1.06 to 2.41), the temperature, with RR by one degree Celsius decline from 1.012 (95 % CI 1.004 to 1.020) to 1.030 (95 % CI 1.023 to 1.037), and wind (3) RR FC windiest days vs. calm days: 1.32 (95 % CI 1.10 to 1.58) to 1.35 (95 % CI 0.88 to 2.08). This review shows that analytic methods are very heterogeneous and poorly adapted to the temporary nature of the data. Studies confirm a certain seasonality, with more fractures in winter and meaningful relationships with meteorological conditions typical of this season.

Keywords Hip fracture · Climate · Epidemiology · Systematic review

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Introduction

Hip fractures constitute a major public health problem (Romley et al. 2013; Kanis et al. 2013), with the mortality rate 1 year after fracture reported as being approximately 20 % (Schneider and Guralnik 1990, R), comparable with that of cardio-infarction. Initially, it was thought that a therapy consisting of moderate exercise and dietary supplements would be effective in preventing hip fractures, and there is still evidence of the effectiveness of these preventive measures (Morgan 2013; Carter and Hinton 2014). However, these mono-therapies have proven insufficient, forcing researchers to rethink the idea that hip fracture prevention can be accomplished without the use of medication. This has spawned the development of numerous drugs for preventing osteoporosis, such as bisphosphonates, female hormone-like drugs, and PTHs, among others. Many countries have thus updated their guidelines for osteoporosis prevention accordingly (NAMS 2010; BCMA 2013).

In contrast, the role of climate in the incidence of hip fracture has received much less attention, so that its real impact has yet to be fully elucidated. The aim of this paper is to examine the evidence gathered thus far to determine which of the various hypotheses on the role of climate in hip fracture incidence (HFi) is the most accurate.

Hip fracture incidence has been analyzed in numerous studies carried out in various geographic areas. The underlying cause of the vast majority of hip fractures is osteoporosis, a metabolic disease. Almost all studies published to date have found a higher HF incidence in women compared to men as well as an increasing incidence associated with the aging of the populations under study (Dennison et al. 2006). In various countries located at different latitudes, increases in HFi seem to correlate with seasonal changes throughout the year, with a greater incidence of HFs in winter (Douglas 1993; Lau et al. 1995; Chiu et al. 1996; Levy et al. 1998; Bulajic-Kopjar 2000; Crawford and Parker 2003; Lin and Xiraxagar 2006).

The role of climate as a determining factor in HFi has been studied for over 30 years, with conclusive research finding changes in bone tissue quality compatible with osteomalacia at certain times of the year in cases of femoral neck fractures (Aaron et al. 1974).

Nevertheless, studies providing empirical evidence for this association using original data, both on climatic conditions and HFi, are fairly recent. In fact, the first such study, published by Caniggia et al., was conducted in Tuscany, Italy, between 1975 and 1985 (Caniggia and Morreale 1989).

Among the hypotheses that attempt to explain the role of seasonal weather patterns in HFi, two have captured special attention in the past few years. Although not mutually exclusive, they represent different causal models. In the first model, the seasonality of HFi is viewed as a consequence of the influence of climate on bone metabolism. Bolstering this hypothesis are the seasonal changes in vitamin D and parathyroid hormone (PTH) levels (Pasco et al. 2004; Bischoff-Ferrari et al. 2008; Cinar et al. 2014), which may be related to the hours of sun exposure. The other hypothesis centers on short-term associations and maintains that HFs are a consequence of the greater risk of suffering a fall in unfavorable weather conditions. This hypothesis explains the positive and significant association found between HF and weather phenomena such as snow or ice in studies conducted in several northern countries (Parker et al. 1996; Levy et al. 1998). Ascertaining which of the two hypotheses better explains the seasonality of HF or calculating the weight of each factor in contributing to this health problem is not a minor issue since they involve vastly different prevention measures. The prevalence of metabolic changes in the coldest seasons and/or the lower sun exposure would favor dietary supplementation or drug therapy to improve metabolic bone status in adults with an increased risk for HF. The hypothesis which views weather as a physical phenomenon that leads to increased risk of falling calls for information campaigns about avoiding situations in which a fall is more likely in the colder seasons.

To date, no systematic review of the evidence on the relationship between weather conditions and hip fracture incidence has been published. It is thus important to review the literature on this subject, not only in search of scientific evidence, but also to ascertain whether the studies that have been conducted can answer relevant questions about the association between seasonal changes and weather patterns and hip fractures.

In this paper, we have systematically collected, evaluated, and summarized those original studies that have linked various climate variables with the incidence of hip fracture.

Material and methods

This is a systematic review which follows specifically the procedure recommended by the MOOSE (meta-analysis of observational studies in epidemiology) protocol for systematic reviews of observational studies (Stroup et al. 2000) and is generally in accordance with PRISMA (preferred reporting items for systematic reviews and meta-analyses) statement (Moher et al. 2009).

Search criteria and study selection

A search was carried out in all the major relevant databases, with the last review taking place in September, 2103. To this end, we selected information sources appropriate for cataloging this type of study: Medline, Embase, and Scopus. We also manually reviewed the list of references in the selected articles in order to find related citations. Finally, we used the Web of Knowledge page to consult the list of articles that shared references with the articles included in the study.

Search strategies and identification of relevant documents

We used the thesauri from Medline (Mesh) and EMBASE (EMTREE). In addition, we used free text searches with truncations (Hip fracture; Climate; Weather; Meteo*).

We included observational studies that analyzed and reported the association between HFi and at least one weather variable. The latter were defined as the principal variables included in the study of meteorology and commonly collected by weather stations, namely temperature, barometric pressure, wind direction and speed, humidity, and precipitation. The search included studies from any geographic location with no restrictions with regard to language.

The resulting search listings included the title and/or abstract (in most articles), which were used to carry out an initial identification of relevant documents.

Two independent researchers participated in this phase of the study. A document was considered relevant if at least one of the observers viewed it as such. The intra-observer agreement was also calculated, giving a Kappa index value of 0.87. The full text of all articles deemed to be relevant was then retrieved.

Data extraction and assessment of methodological quality

Methodological quality was assessed independently by two observers according to CASPe templates (Critical Appraisal Skills Programme—Spanish) for cohort studies and/or with Osteba checklists for case series.

For each article retrieved, we extracted data related to geographic location and time (latitude, longitude, study period), sample data (cause of HF, diagnostic method, number of patients, percentage of women, and average age), HF incidence, meteorological data (data sources, weather variables), analytical methods (statistical methods), and outcomes (measures of association).

Data analysis

Information was also collected on the association between HFi and the climatic variables used in each study. In cases where results were available from three or more studies, we conducted a meta-analysis using estimates of associations.

Results

Of a total of 134 studies retrieved, 20 were selected as relevant (Fig. 1). The main features of the selected studies are summarized in Table 1.

Study periods and geographic location

The earliest study was published in 1989 (Caniggia and Morreale 1989), but analyzed the association between climate and HF from a much earlier period, namely 1975. The study examining the most recent period is that by Murray et al. (Murray et al. 2011), which includes the first part of 2010.

Study period durations differ between studies, from 1 year (Parker and Martin 1994; Lofthus et al. 2001; Atherton et al. 2005) to up to more than 10 years of follow-up (Levy et al. 1998; Caniggia and Morreale 1989; Jacobsen et al. 1995; Mirchandani et al. 2005; Tenías et al. 2009; Modarres et al. 2012). Longer study periods may not only give a more accurate picture of the role of weather phenomena in this health problem, but also serve to distinguish the cyclical component of seasonality.

The studies were conducted in 18 different locations, 16 of which are situated in the Northern Hemisphere. The latitudes of the study locations in the Northern Hemisphere ranged from 59.91° (Oslo) to 22.40° (Hong Kong), while in the Southern Hemisphere, they ranged from −31,25° to −33,87° both in New South Wales, Australia. (Lau et al. 1995; Turner et al. 2011).

The studies collected were mainly conducted in northern countries such as the UK (Parker and Martin 1994; Chesser et al. 2002; Atherton et al. 2005; Murray et al. 2011), Scandinavia (Lauritzen et al. 1993; Lofthus et al. 2001; Frihagen et al. 2011), Central Europe (Burget et al. 2012), and North America [Jacobsen et al. 1995; Levy et al. 1998; Mirchandani et al. 2005; Bischoff-Ferrari et al. 2007; Modarres et al. 2012]. Studies from southern countries remain scarce (Caniggia and Morreale 1989; Tenías et al. 2009; Furelos et al. 2001). We also identified two studies carried out in Asia (Chiu et al. 1996; Lin and Xiraxagar 2006) and another two in Australia (Lau et al. 1995; Turner et al. 2011).

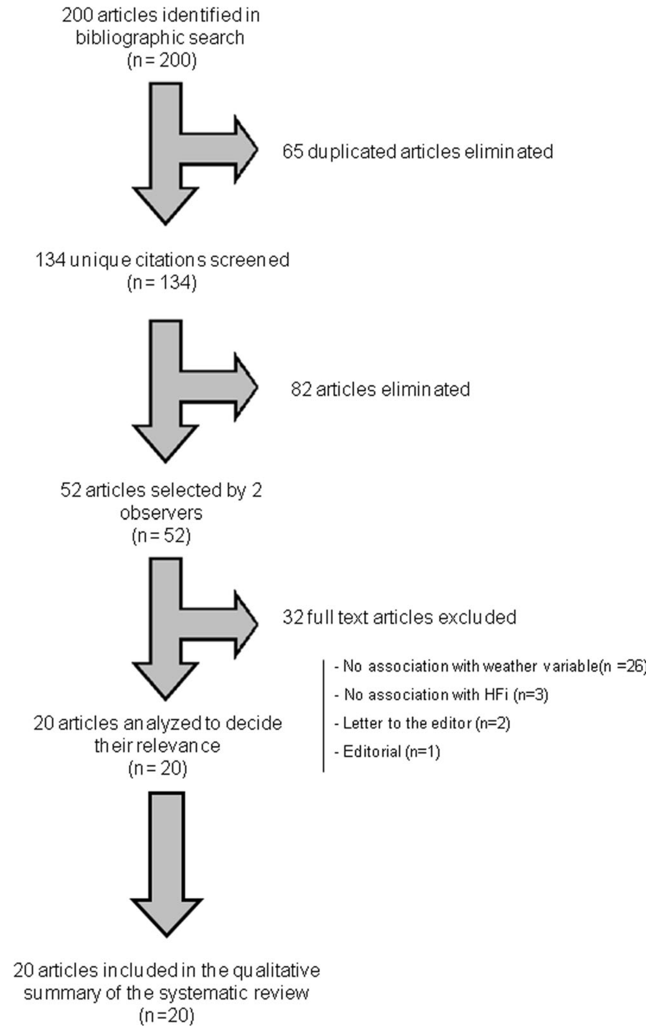

Fig. 1 Flow chart of studies retrieved and finally included in the systematic review

Identification of hip fracture cases

Identification of cases of HF was performed with the aid of emergency room or hospital admission records when the admission diagnosis was listed as hip fracture with either an ICD-9 code 820 or ICD-10 code S72 classification (Turner et al. 2011). Most studies specified the exclusion criteria used, which included high velocity trauma (traffic accidents),

Table 1 Weather condition and hip fractures: main features of the selected studies

Reference	Location	Identification of HF cases	Age, HF incidence	Meteorological variables	Statistical Methods	Results
Caniggia and Morreale 1989	Tuscany, Italy 1975–1985	1567 HF treated in Department of Orthopaedics, University of Siena, Italy Excluded traffic accidents and tumorous or infective disease	Patients over 50 years of age Incidence Rate of HF in women per 100,000=16.35 Incidence Rate of HF in men per 100,000=5.30	Temperature Cloud cover Rainfall Ultraviolet radiation Meteorological Observatory in Siena	Linear regression UA: month	No association
Lauritzen et al. 1993	Copenhagen, Denmark 1976–1984	HF according to ICD-9M treated in Hvidovre Hospital, Copenhagen, Denmark	Women over 19 years of age	Snowy weather Icy weather Meteorological Office in Copenhagen	Linear regression UA: day	No association with HF ($p=0.19$, $r^2=0.05$)
Parker and Martin 1994	Birmingham, UK na	429 acute HF admitted to the Birmingham Accident Hospital Excluded falls in hospital, no history of a fall	Patients over 60 years of age 85 % female 72 % living within their own homes Urban population	Temperature Air frost Ground frost Birmingham University Weather Centre	Not stated UA: day	Slight association between day of fall and ground frost ($p=0.04$) No significant association for air frost or minimum daily temperature No seasonal variance in incidence of HF
Jacobsen et al. 1995	Rochester, Minnesota, USA 1952–1989	1147 HF from medical record system Excluded severe trauma or pathological causes	Women over 44 years of age Incidence rate of HF per 100,000=292	Snow Freezing rain, freezing drizzle, or frost High wind Rain or drizzle National Weather Service, Rochester	Poisson regression Models were constructed for younger (<75) and older(>75) women UA: day	<75 years: - RR snow/blowing snow 1.22 (0.91 – 1.63) - RR Freezing rain, drizzle or frost 1.60 (1.06 – 2.41) >=75 years: RR high wind 1.35 (0.88-2.08)
Lau et al. 1995	New South Wales, Australia 1981, 1983, 1986, 1988–1990	Primary diagnosis of HF (ICD 820) from hospital admission data for NSW Department of Health	Patients over 50 years of age Incidence rate of HF per 100,000=30	Mean daily minimum temperature (°C) Mean cloud cover Number of days with strong wind Number of days with fog Number of days with mist Number of days with rainfall Observatory Hill in Sydney	Poisson regression. Models were constructed for younger (<75) and older patients (>75) UA: month	RR for a 5 °C decrease in mean daily minimum temperature over the month <75 years: RR=1.12 (1.06-1.17) >=75 years: RR=1.16 (1.12-1.20). Remaining variables not statistically significant
Chiu et al. 1996	Hong Kong, China 1986–1990	1500 elderly patients with surgically treated HF Excluded: high velocity trauma, pathological fractures	Patients over 50 years of age 462 men/1038 women	Average highest, mean, and lowest ambient temperature Average relative humidity Amount of rainfall Government observatory	Linear regression UA: month	Lowest temperature and lower relative humidity related with greater number of HF in that month.
Levy et al. 1998	Montreal, Canada	18,455 patients hospitalized with	Patients over 50 years of age	Maximum temperature Quantity of rain	Poisson regression UA: day	Women:

Table 1 (continued)

Reference	Location	Identification of HF cases	Age, HF incidence	Meteorological variables	Statistical Methods	Results
	April 1982–March 1992	a primary discharge diagnosis of "Fracture of neck of femur" (ICD-9 code 820) Excluded: HF as a secondary diagnosis, secondary diagnosis of cancer, accident date missing	14,167 (77 %) women and 4288 (23 %) men	Snow Freezing precipitation (freezing rain, freezing drizzle, and ice pellets) Environment Canada weather station, Quebec		RR Max. temperature<−5 °C, no rain or snow 1.13 (1.02 – 1.25) RR Any freezing precipitation 1.14 (1.04 – 1.24) Men: RR Any freezing precipitation 1.36 (1.17 – 1.58) Warm (>5°), rainy days were protective for HF. Cold (<5°), wet, snowy days were associated with increased rates of HF. Women strongest association among 50–64 years Women >80 years no association.
Furelos et al. 2001	Lugo, Spain 1992–995	457 patients hospitalized with a diagnosis of HF Excluded: high velocity trauma, pathological fractures	Patients over 60 years of age 359 women and 98 men 83±8.9 years (60–90) Incidence rate of HF per 100,000=285	Mean daily temperature (°C) Midday relative humidity (%) Atmospheric pressure (hPa) Midday visibility (dm) Regional Meteorological Centre	Chi-square, *t*-test, ANOVA UA: day	No association
Lofthus et al. 2001	Oslo, Norway May 1996–April 1997.	1291 patients/1316 fractures from electronic diagnosis registers of 4 hospitals of Oslo (ICD9 820.X) and list of the operating theater of 3 hospitals with emergency service. Excluded: fracture distal to the lesser trochanter, fracture only intersecting the greater trochanter, fracture due to cancer metastases	0-90 years 82.1±9.3 years for women 76.6±12.8 years for men 78 % women Incidence rate of HF in women ≥50 years per 100,000=118 Incidence rate of HF in men ≥50 years per 100,000: 44	Outdoor temperature Norwegian Meteorological Institute	Chi-square Pearson correlation UA: month	No significant difference in the distribution of HF over 12 months. Correlation between outdoor temperature and HF for each month 1996/97: r=−0.52 (p=0.08) 67 % HF occurred indoors
Chesser et al. 2002	Bristol, UK Five year period	818 patients presented to one district general hospital with a HF (cervical/pertrochanteric).	>65 years 622 women and 196 men P50=83 years (65–103)	Maximum and minimum daily temperatures (range of 5 °C) Bristol Weather Centre	Chi-square Mann-Whitney Kruskall-Wallis UA: day	No relationship between outside temperature and incidence of HF. No significant change in HF per month or season

Table 1 (continued)

Reference	Location	Identification of HF cases	Age, HF incidence	Meteorological variables	Statistical Methods	Results
		Excluded: high velocity trauma, pathological fractures				
Atherton et al. 2005	Leicester, UK January 1998–December 1998	693 adult admissions with proximal femoral fractures	Adult	Maximum temperature (5 °C intervals) Minimum temperature (5 °C intervals) Rainfall (10 mm intervals) Sunshine (1 h intervals) Significant weather conditions (snow/hail/ice/fog) Meteorological Office	Poisson regression UA: day	No relationship between weather variables and incidence of HF Incidence rate ratios (IRR) for day of week for NOF trauma: Monday IRR 1.67 (1.32-2.13) $p<0.001$ Tuesday IRR 1.56 (1.23-2.00) $p<0.001$ Wednesday IRR 1.57 (1.24-2.01) $p<0.001$
Mirchandani et al. 2005	New York, USA 1985–1996	66,346 residents of NYC with HF as primary reason for admission Database SPARCS Excluded: subtrochanteric and pathological fractures	≥65 years 79.3 % women Mean age 81.7 years Incidence rate of HF per 100,000 was 4.5 in the study period	Maximum daily temperature (°F) Minimum daily temperature (°F) Amount of precipitation (inches) Amount of snowfall (inches) Depth of snow on the ground (inches) Amount of sunshine (minutes/day) Percent of possible sunshine Average daily wind speed (mph) Maximum relative humidity Climatologist and National Climatic Data Centre	Chi-square Pearson correlation UA: month	Minimum daily temperature $r=0.167$ $p<0.001$ Average daily wind speed $r=0.166$ $p<0.001$ Maximum daily temperature $r=0.155$ $p<0.001$ HF incidence rates were higher in winter than summer December and January were the peak months for HF
Lin and Xiraxagar 2006	Taiwan 1997–2003	102,385 inpatients diagnosed with HF (ICD 820). Data from Taiwan's NHI Excluded: readmissions and pathological fractures	≥45 years Mean age 75.4 years (SD=10.5) 58.1 % female 59.3 % older than 75 years Female to male ratio 1.39 Incidence rate of HF per 100,000 in the study period was 19.2	Hours of daily sunshine Ambient temperature Maximum and minimum temperature Relative humidity Atmospheric pressure Rainfall 19 weather bureau observatories of Taiwan	ARIMA UA: month	Seasonality: high rates in November-February Negative association with mean ambient temperature: - males ($b=-0.280$) - females ($b=-0.341$) - 65–74 y ($b=-0.241$) ->=75 y ($b=-2.263$) - 45–64 y: NS HF rates tended to be higher in Jan and Nov and lower in May by gender and age

Table 1 (continued)

Reference	Location	Identification of HF cases	Age, HF incidence	Meteorological variables	Statistical Methods	Results
			(monthly rate) and 230.4 (annual rate)			
Bischoff-Ferrari et al. 2007	USA July 1986–June 1990	35,007 HF from 5 % sample of the US Medicare population over age 65 residing in all 50 states (ICD9-CM 820–820.9 or CPT-4 27230–27248)	>65 years 78.8 % female 94.9 % white race	Snowfall Sunshine (number of sunny days) Mean daily temperature National Oceanic and Atmospheric Administration website	Poisson regression UA: month	RR HF per 20 inches of annual snowfall was 0.95 (95 % CI 0.91-0.99) In summer HF risk was highest in hotter locations (RR HP per 10 °F=1.07 [95 % CI 1.02-1.12]) In summer RR HF per 14 sunny days=0.97 (95 % CI 0.94-1.01) In spring and fall RR HF per 14 sunny fall days=0.94 (95 % CI 0.90-0.99)
Tenías et al. 2009	Valencia, Spain 1996-2005	2121 patients with principal diagnosis of a HF (CID-9-CM 820.00-820.9) who lived in Health area 14 of the Autonomous Region of Valencia Cases were taken from National Records of the Minimum Basic Data Set (MBDS) of the Ministry of Health Excluded: suspected non-osteoporotic HF, traffic accidents	>45 75.3 % Female 77.1 % >75 years 47.8 % pertrochanteric area	Temperature (minimum, maximum, mean) Relative humidity (minimum, maximum, mean) Precipitation (in ml, daily) Incidence of snow, hail, storm, fog, dew and frost Wind gales (number of periods of calm, in tenths of an hour) Regional Weather Center	Poisson regression Case-crossover design UA: day	Case-crossover analysis: periods of calm wind on the day prior to the event was the only variable associated to the incidence of HF. The windiest days (quartile 4) were associated with a 32 % increased risk of HF (OR 1.32 CI 95 % 1.10–1.58) with respect to the calmest days (quartile 1)
Murray et al. 2011	Edinburgh, UK December 2008–January 2009 December 2009–January 2010	Patients presenting with fractures to accident and emergency departments and a minor injuries unit. Data were collected from electronic case notes	na	Maximum, minimum, and ground temperature State of ground (ice, snow but not ice, neither snow nor ice) Icy roads warning Heavy snow warning Meteorological Office	Pearson correlation Linear regression UA: day	No significant correlation between any weather ariable and HF.
Frihagen et al. 2011	Oslo, Norway 1996-1997	1312 HF identified through search in ischarge registers	>20 years Ratio male/female 1 to 4 Mean age 79 years for men	Snow fall Temperature around zero (temperatures below and above 0 °C the same day) The Norwegian Meteorological Institute	*t* test UA: day	For days with snow (n=63) 4.2 HF occurred daily compared with 3.5 on winter days without snow (p=0.01)

Table 1 (continued)

Reference	Location	Identification of HF cases	Age, HF incidence	Meteorological variables	Statistical Methods	Results
			Mean age 82 years for women			
Turner et al. 2011	Sidney, Australia July 1998–December 2004	Diagnosis code for HF (CIE 10 S72.0-S72.2) from New South Wales Admitted Patients Data Collection	≥65 years	Mean daily temperature for the Sydney statistical division based on the daily average temperature at each station Bureau of Meteorology (22 stations)	Poisson regression UA: day	A 1 °C decrease in temperature is associated with 1-2 % increase in HF rates RR 1 °C 75 – 84 years old Male 0.98 (0.96 – 0.99) Female 0,99 (0,98 – 1.00) 85+ years old Male 0.98 (0.96 – 1.00) Female 0.98 (0.97 – 0.99)
Modarres et al. 2012	Montreal, Canada 1993–2004	22,855 patients admited with a diagnosis of HF (ICD-9 codes 820.X) from Quebec's hospital discharge register Excluded: accidental fall (ICD-9 codes E880-E888), accidents due to natural or environmental factors (E900-E909)	≥40 years 4 group age-sex: 40–74 (F1, M1), ≥75 (F2, M2). 75.8 % females f/m group 1: 1.7 f/m group 2: 4.01	Temperature Precipitation Snow Wind Sunshine Meteorological stations in Montreal	SARIMA Pearson correlation Non parametric Wilcoxon, Levene UA: month	Significant negative correlation with temperature Significant positive correlation with snow depth and number of snowy days Significant negative correlation with rainfall depth and number of rainy days Significant negative correlation with total hours of sunshine
Burget et al. 2012	Prague and Ostrava, Czech Republic 2001–2005	1720 patients admitted to Surgery (Prague) and Traumatology (Ostrava) Departments (ICD-9) Excluded: Pathological HF, traffic accidents	>60 years	Temperature Relative Humidity Atmospheric pressure Wind speed Visibility Weather website	Pearson correlation *t* test UA: day	No significant correlation between any weather variable and HF.

na not available

pathological fractures (tumor or infectious disease), no history of a fall (Parker and Martin 1994), subtrochanteric fractures (Lofthus et al. 2001; Mirchandani et al. 2005), or readmissions (Lin and Xiraxagar 2006).

The studies used various cutoff points to classify the age of the subjects. These ranged from groups of subjects aged 40 and over to groups of subjects aged 65 and over. Four studies collected data on HF in younger subjects (Lauritzen et al. 1993; Lofthus et al. 2001; Atherton et al. 2005; Frihagen et al. 2011) while one study did not specify subject age (Murray et al. 2011).

Weather variables analyzed

In all cases, the sources of information on meteorological variables were official weather stations close to the respective study areas.

A total of 15 weather variables were analyzed in the various studies, with the most commonly analyzed being (in descending order): temperature (18 studies), precipitation (10), snow (10), icy weather (7), wind (5), relative humidity (5), and sunshine (5).

Statistical methods

The majority of studies utilized regression analysis, with Poisson regression (Douglas 1993) and linear regression (Chiu et al. 1996) predominating. Only two studies used ARIMA modeling (Lin and Xiraxagar 2006; Modarres et al. 2012). Modarres et al. (2014) reanalyzes the series with a nonlinear time series modeling approach (ARMAX-GARCH).

The remaining studies analyzed data using Pearson linear correlation coefficients (Chiu et al. 1996) or other types of tests of comparisons (Levy et al. 1998), e.g., an ANOVA or a *t* test. One of the studies did not specify which type of analytical method was used.

The unit of analysis used in 12 studies was one day while in the remaining studies it was one month.

Associations

The results obtained are quite heterogeneous, although there is an observable trend in the results for temperature, snow, ice, and sun exposure.

For temperature, despite the different methods, variables, and units of analysis used, most studies show a negative association with the incidence of hip fracture. Thus, of the 18 papers analyzing the relationship between temperature and the incidence of hip fracture, 10 found a significant association while 8 did not. Figure 2 shows the estimates of association found in those studies that quantified this relationship.

Almost without exception, snow and ice showed a positive association with the occurrence of HF at all latitudes where studies were conducted.

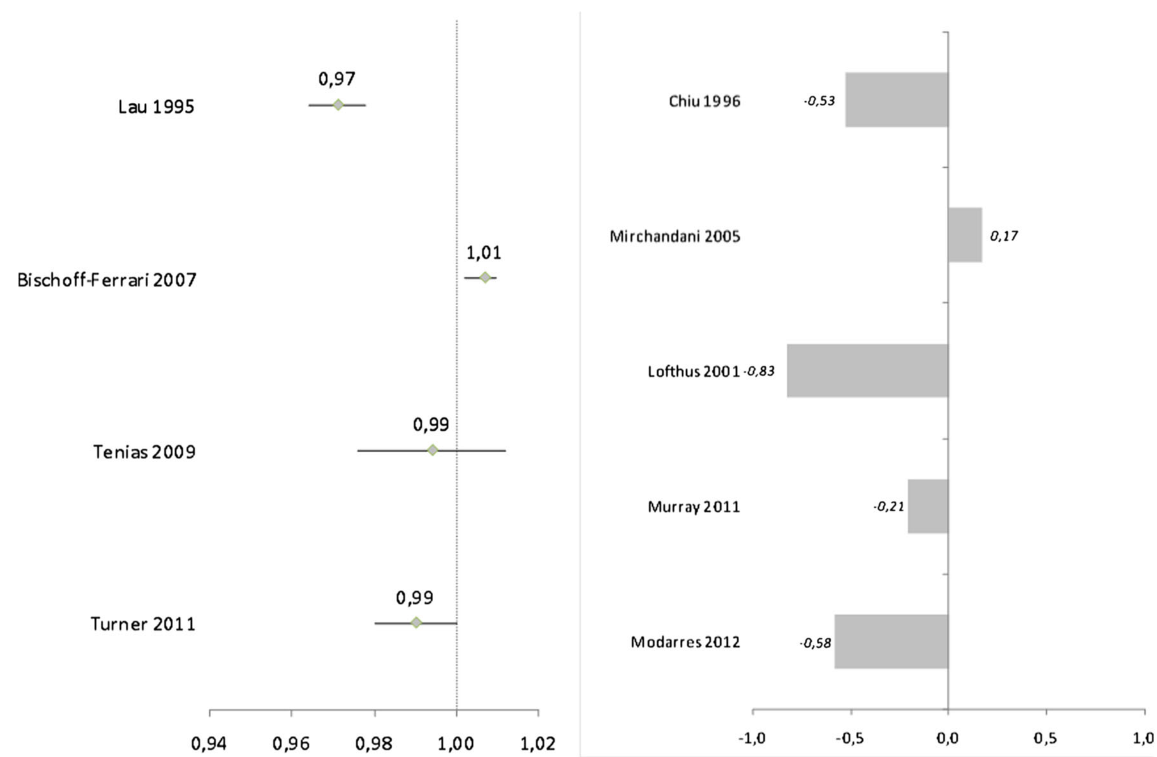

Fig. 2 Hip fracture risk ratios associated to 1 °C temperature increase (*left panel*). Correlation coefficients between temperature and hip fracture incidence (*right panel*)

Studies analyzing some indicator of sun exposure generally used monthly aggregates and showed a negative association with HFi.

The associations between the remaining indicators (precipitation, wind, fog, and atmospheric pressure) and HFi were less consistent, giving both positive and negative associations, usually close to the null value.

Discussion

For this systematic review, we identified and analyzed the relevant empirical evidence published to date examining the relationship between weather conditions and HFi.

The selected studies differ greatly in their design and analysis strategy, making it difficult to compare results. Nevertheless, there is a consistent relationship between HFi and several of the climate variables examined, including temperature, snow, ice, and sun exposure, regardless of location, study design, and analysis strategy used.

Overall, there was an increase in the incidence of HF in the colder months.

Air temperature was perhaps the first meteorological variable to be measured using standardized methods, with reasonably reliable instrumental records of surface temperature with almost global coverage dating from 1850. Temperature is also the variable that best represents seasonal changes. It is partly for this reason that associations between temperature and HFi mostly encompass the seasonal changes observed in HFi time series. It remains unclear if the relationship between temperature and HF is direct or whether it is mediated by other closely related variables, such as sun exposure. In the short term, cold temperatures can cause, among other effects, numbness, which can in turn lead to clumsiness or a lack of coordination in the elderly, increasing the risk of falls. It has been suggested that the underlying cause of HF in patients who have suffered a fall may be a subclinical hypothermia that impairs motor coordination (Bastow et al. 1983). Several authors even point to the influence that an excess of clothing can have on mobility and balance in the elderly (Chiu et al. 1996).

The causal mechanism associated with snow and ice has a simpler, more direct explanation. Falls are more frequent under these conditions (Morency et al. 2012; Beynon et al. 2011), with the increased risk of HF and other types of fractures being frequently observed (Lauritzen et al. 1993; Parker and Martin 1994; Jacobsen et al. 1995; Levy et al. 1998; Bischoff-Ferrari et al. 2007; Frihagen et al. 2011; Modarres et al. 2012).

Sun exposure appears to be an important determinant for bone metabolism (Lips 2001; Bischoff-Ferrari et al. 2011; Bischoff-Ferrari 2012). Indeed, a relationship between sun exposure and levels of vitamin D, PTH, and other bone metabolic indicators has been observed and documented. Furthermore, these associations have been analyzed in the medium term, with monthly (not daily) time aggregates, which makes the relationship more plausible due to the necessary induction period.

Wind, described in several classic epidemiological treatises (Rothman 2012) as an example of an immediate precipitating cause of HFs, has been analyzed in very few studies (Jacobsen et al. 1995; Lau et al. 1995; Mirchandani et al. 2005; Tenías et al. 2009; Modarres et al. 2012). Although a positive association has generally been observed between HFi and both wind duration (Tenías et al. 2009) and speed (Jacobsen et al. 1995; Lau et al. 1995; Mirchandani et al. 2005; Modarres et al. 2012), the small number of studies renders the results inconclusive.

The associations found for the rest of the variables included in our systematic review are much more inconsistent. Either they have been analyzed only sporadically, as is the case with atmospheric pressure, or the results have been so heterogeneous that no general conclusions can be made (relative humidity, precipitation, fog, and other weather conditions).

Particularly striking is the variety of methodological approaches and, above all, of analytical methods used. Virtually, all the publications we found are ecological time series studies, with aggregated measurements (ecological) of both the exposure (weather phenomenon) and the outcome (fracture). Ecological studies have several well-known limitations, including the so-called ecological fallacy (Morgenstern 1995), although time series designs are somewhat less vulnerable to this type of bias than geographic studies. The only exception to this is the study conducted by Tenías et al. (2009), which used a mixed design including ecological methods for exposure and individual analysis for the outcome point. Most studies (Bischoff-Ferrari et al. 2008) use 1 day as the unit of analysis, whereas the rest (Lin and Xiraxagar 2006) use 1 month. The former would be the ideal unit of analysis to study short-term associations while the latter would be better for those that occur in the medium to long-term.

Unfortunately, in many cases, the statistical analysis used is ill suited to the nature of the data. Serial autocorrelation, typical of time series, cannot be adequately controlled for in the absence of specific methods of analysis (e.g., ARIMA) or regression models in which the main components of the time series (trend, seasonality) are controlled for. Even in these cases, the possibility of residual overdispersion would speak for the use of other models that take this phenomenon into account, such as negative binomial regression. The consequence of using a method of analysis that does not take into account the nature of the data may be reflected primarily in the estimates of the standard errors of the regression coefficients, with an overestimation of statistical significance. Recently, nonlinear time series modeling shows that climate variables and HFi doesn't change linearly with time, and increase exponentially when weather conditions are more adverse (Modarres et al. 2014).

Other possible sources of heterogeneity are subject age, the use of different cutoff points, the type of register used to identify HF cases, and the various exclusion criteria applied (pathological fractures, traffic accidents, etc.). For this reason, we have avoided the temptation of showing results that are solely the product of a meta-analysis, opting instead for a narrative interpretation of the results.

Implications for clinical practice and public health

The ability to intervene with regard to exposure is limited (except for measures that can be put in place to influence climate change), but various preventive measures of a different nature can be implemented. These could include, in the long term, the introduction of alternative therapies to improve bone metabolism (e.g., vitamin D supplementation) at certain times of the year while short-term measures could include information campaigns to lower the risk of falls in elderly patients.

As mentioned in the introduction, there are two main hypotheses explaining the relationship between atmospheric conditions and hip fracture incidence. Although the evidence to date does not allow us to fully rule out either of them in order to confirm one hypothesis over the other, our systematic review of the data supports the idea of short-term associations and the hypothesis that HFs are a consequence of the greater risk of suffering a fall in unfavorable weather conditions.

Advice for future research

Above all, it is necessary to implement multicenter studies with a commonly agreed upon methodology in order to analyze the relationship between weather patterns and HFi in different representative locations. A paradigmatic example of this approach is the European project APHEA, which has managed to conduct a multicenter study of the association between air pollution and various health indicators in various European cities (Katsouyanni et al. 1996).

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