Bone 50 (2012) 909–916

Contents lists available at SciVerse ScienceDirect

Bone

journal homepage: www.elsevier.com/locate/bone

Original Full Length Article

Modeling seasonal variation of hip fracture in Montreal, Canada

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ARTICLE INFO

Article history:
Received 8 June 2011
Revised 4 January 2012
Accepted 9 January 2012
Available online 16 January 2012

Edited by: Robert Recker

Keywords:
Hip fracture
SARIMA
Seasonality
Trend
Climate

ABSTRACT

The investigation of the association of the climate variables with hip fracture incidences is important in social health issues. This study examined and modeled the seasonal variation of monthly population based hip fracture rate (HFr) time series. The seasonal ARIMA time series modeling approach is used to model monthly HFr incidences time series of female and male patients of the ages 40–74 and 75+ of Montreal, Québec province, Canada, in the period of 1993–2004. The correlation coefficients between meteorological variables such as temperature, snow depth, rainfall depth and day length and HFr are significant. The nonparametric Mann–Kendall test for trend assessment and the nonparametric Levene's test and Wilcoxon's test for checking the difference of HFr before and after change point are also used. The seasonality in HFr indicated sharp difference between winter and summer time. The trend assessment showed decreasing trends in HFr of female and male groups. The nonparametric test also indicated a significant change of the mean HFr. A seasonal ARIMA model was applied for HFr time series without trend and a time trend ARIMA model (TT-ARIMA) was developed and fitted to HFr time series with a significant trend. The multi criteria evaluation showed the adequacy of SARIMA and TT-ARIMA models for modeling seasonal hip fracture time series with and without significant trend. In the time series analysis of HFr of the Montreal region, the effects of the seasonal variation of climate variables on hip fracture are clear. The Seasonal ARIMA model is useful for modeling HFr time series without trend. However, for time series with significant trend, the TT-ARIMA model should be applied for modeling HFr time series.

Introduction

The incidence of hip fracture (HF) has taken a considerable attention in the recent decades as the population of the developing countries is becoming older and the associated burden is increasing because of the high cost for the health system, the morbidity and the excess of mortality of the elderly people especially within the first year after the fracture [1]. Many investigations in different countries and different regions within a country have shown hip fracture rate variation due to different factors such as socioeconomic level, lifestyle, physical and genetic characteristics, the degree of economic development and the health care system characteristics [2–4]. The relationship between climatic factors and their impacts on the seasonal variation of hip fracture incidences have also been the subject of many studies.

Seasonal variation of hip fractures has been documented in different geographical regions with different climatic characteristics. From the cold high latitude countries such as Canada, Sweden and Norway [5–7] to warm climate countries and tropical countries in northern and southern hemispheres [2,3,8–10], the seasonal variation of hip fracture data has been studied. All these studies have shown seasonal variations of hip fracture incidence. Various hypothetical causal mechanisms for the seasonal variation of hip fracture could be considered. For example, the seasonality of sunlight in winter and summer time and its influence on the variation of the vitamin D synthesis in the skin [11,12] which, itself, affects both bone density and muscle strength and can affect particularly the mobility and resistance to falls among elderly people was mentioned by some studies [13,14]. Freezing temperatures, snow and ice in winter may increase the risk of slipping among younger people [11].

The hip fracture incidences may change through time due to the increasing of the population of aged people, especially in the developed countries, and due to change in meteorological variables (climate change). Therefore, it is necessary to investigate the change of hip fracture and to model the seasonal variation of hip fracture data according to climatic variables through a statistical framework. There are many studies in the literature which consider statistical modeling and assess the change in the hip fracture incidence.

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doi:10.1016/j.bone.2012.01.004

The Poisson regression model has been used to study the association of the seasonal weather with hip fracture incidence in some states of the United States [15]. For monthly hip fracture rates of Scotland, Hong Kong and New Zealand, the cosine and sine curves of time trend were fitted and different seasonal peaks of hip fracture were reported [16]. The time series modeling approach has also been used for modeling seasonal variation of hip fracture data and its relationship to climatic variables [10]. However the methodological approaches employed in the majority of studies remain simple and less suitable to model hip fracture time series. Specific temporal approaches have to be applied to better describe and understand secular trends together with the seasonality of hip fractures.

Although the costs associated with treatments of hip fractures in Canada were estimated $280 million in 1988 and $1.3 billion in 1993, there are few reports and researches on the association of hip fracture rates with climate variables. For example, no seasonal effects on hip fracture (HF) incidences were identified for Ontario, British Columbia and Alberta for both men and women [17]. For Québec province, in the period of 1981–1992, no significant secular trend was observed using Poisson regression model but there was a marked seasonal variation in the occurrence of hip fracture with high risk at winter time [18]. Based on the Canadian Institute of Health Information (CIHI) database from 1985 to 2005, there was a decrease in age-specific hip fracture rates of 31.8% and 25% in females and males, respectively with a change point of hip fracture rates in 1996. For the overall population, the average age adjusted annual percentage decrease in hip fracture rates was 1.2% for 1985–1996 and 2.4% for 1996–2005 [19].

The aim of this study is to investigate the association of hip fracture and climate variables and to model the seasonal variation of hip fracture incidence in the Montreal region (Quebec province, Canada) between 1993 and 2004 by the use of a popular autoregressive moving average model.

Methods

Studied population and data sources

The population of this study includes all the residents of the age 40 years and older in the Montreal region between January 1, 1993 and December 31, 2004. The Montreal region consists of two health administrative regions (Laval and Montreal) with a population at risk of 1,077,813 individuals in 2004 (Ministère de la Santé et des Services Sociaux du Québec 2005,[20]).

Hospital discharge data were obtained from the Quebec's hospital discharge register '*Maintenance et Exploitation des Données pour l'Étude de la Clientèle Hospitalière (MED-ECHO)*'. Hip fractures were recorded if: (a) the patient was a resident of the Montreal region, (b) the patient was aged of ≥40 years and (c) the main diagnosis of the admission was a hip fracture (ICD-9 codes 820.X). Records from individuals whose injury external cause was other than "accidental fall" (ICD-9 codes E880 to E888) or "accidents due to natural and environmental factors" (ICD-9 codes E900 to E909) were excluded. Hospitalisations of the same patient with the main diagnosis of hip fracture in the period of 365 days were considered as one event. Hospitalisations occurring in a period longer than 365 days were considered as two distinct events. The date of the hospitalization was considered as the date of the hip fracture. Population estimates for each health region by the calendar year between 1993 and 2004 were supplied by the Ministère de la santé et des services sociaux of Quebec [20].

Hip fracture data

The annual and the monthly number of hip fractures were calculated for female and male patients separately for two age-groups, 40–74 years and 75 years and older. We use the following notations for these groups: F1 and M1 for females and males of ages 40–74 years and F2 and M2 for females and males of at age ≥ 75 years, hereafter, respectively. The monthly number of hip fractures was adjusted to its 30.4-day equivalent to compensate for the unequal number of days in each calendar month [21].

Age-standardized hip fracture rates for 100,000 person-years and for 100,000 person-months were calculated for each group and direct-adjusted to the 2004 age structure of the Montreal region to allow for comparison over time. The denominators were the population estimates for each calendar year. The hip fracture (HF) and hip fracture rate (HFr) time series are illustrated in Fig. 1.

Meteorological variables

The meteorological data are used in this study to find the relationship between climatic factors and HFr and to evaluate the seasonal variation of hip fracture incidences. In order to establish this relationship in a regional scale, we apply meteorological data from 9 stations in the Montreal region. The monthly variables are selected in the period of 1993–2004 as a common available data period in these stations. The average of each variable for each month was then calculated to have a single monthly time series.

Different types of climate variables such as temperature, precipitation, snow, wind and sunshine, in different statistics such as maximum, minimum, mean, total sum and the number of days within a monthly time scale have been gathered in order to investigate their seasonal effects on hip fracture incidences. These variables also allow investigating the effect of both extreme and mean climate conditions on hip fracture incidences.

Statistical methods

As the seasonality is a general component of monthly time series, the autoregressive integrated moving average (ARIMA) modeling approach is used to build a model of seasonal variation of HFr of the Montreal region. The seasonal ARIMA or SARIMA model assumes that the current observation is related to the past observations through time. The general multiplicative form of a SARIMA model is written as SARIMA $(p,d,q)\times(P,D,Q)$. This model has nonseasonal autoregressive and moving average parameters of order p and q, seasonal autoregressive and moving average parameters of order P and Q and two nonseasonal and seasonal differencing of orders d and D, respectively.

For fitting a time series model to hip fracture data, one should select the type and the order of the parameters of the model (p, q, P, Q) according to temporal (seasonal) variation of the observed time series and then estimate the parameters of the selected models. The parameters of SARIMA models may be estimated by either the method of moments or by the method of least square. In this study, the method of maximum likelihood method which is approximately equivalent to the method of least square is applied. These parameters of the models should be statistically significant and efficient. In other words, the parameters should be statistically different from zero to be kept in the model. When one or some candidate SARIMA models are selected, the final step of modeling or the diagnostic checking is carried out. This includes testing the non-existence of autocorrelation structure in the residuals of the model. The popular Ljung–Box statistics is applied in this step to check the autocorrelation structure of the residuals. The model selection is an iterative procedure and should be repeated until the best model is identified [22].

Two key assumptions of the SARIMA models are the dependence of an observation to the past observations and the stationarity of the statistical moments through time. Before applying the SARIMA model for monthly hip fracture time series, it is necessary to check the existence of trend or nonstationarity in HFr time series.

To examine the existence of nonstationarity in HFr data sets, the nonparametric Mann–Kendall (MK) test is applied. The MK test measures the degree of correspondence between two ranking variables

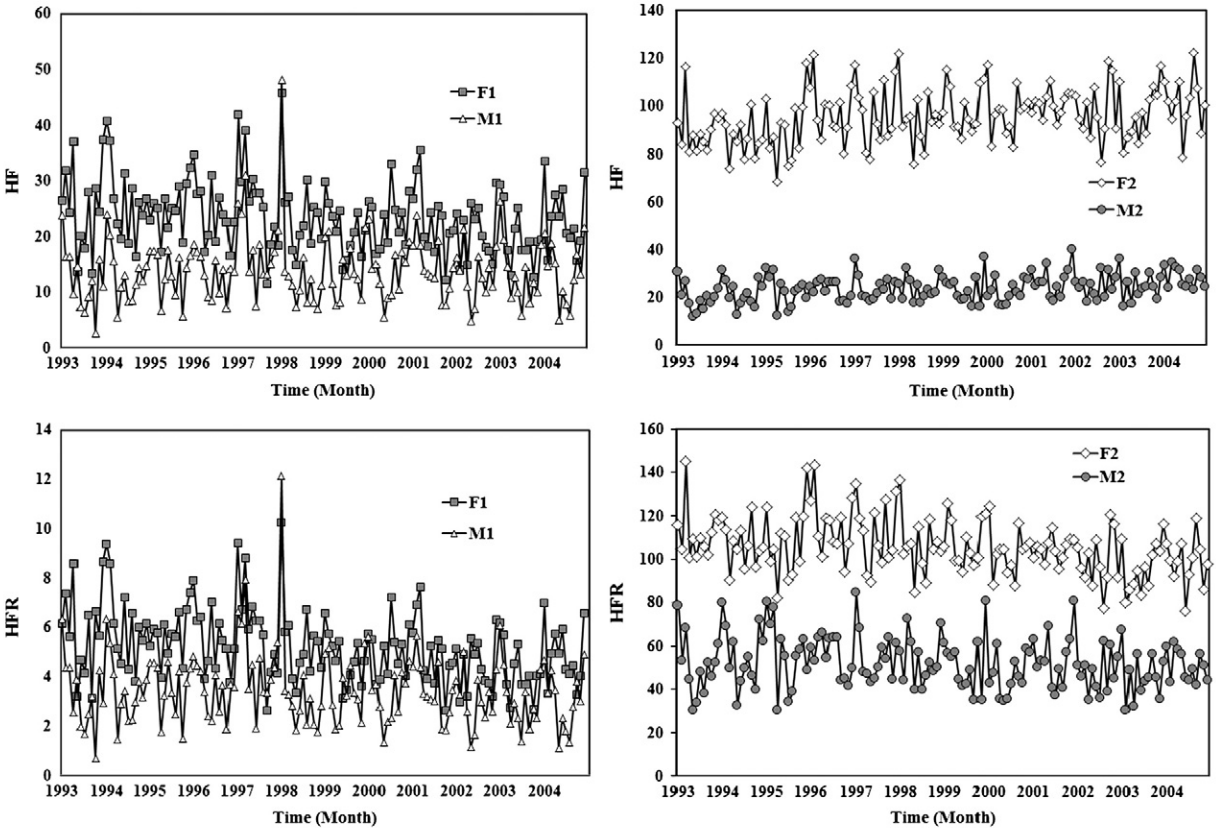

Fig. 1. Monthly HF and HFr time series for different groups during 1993–2004.

and assesses the significance of this correspondence. The positive value of the standardized MK statistics shows an increasing trend while the negative value indicates a decreasing trend. The null hypothesis of no trend cannot be rejected if $p > 0.05$. Otherwise, trend of hip fracture data is statistically significant.

In the presence of trend, we also apply two nonparametric tests to evaluate the change in the mean and the standard deviation of HFr data sets, namely the Wilcoxon rank sum test for the equality of the mean and the Levene's test for the equality of the standard deviation. These nonparametric tests are applied for the HFr time series before and after the change point identified by a simple method based on the cumulative standardized HFr time series. The comparison of the HFr statistical parameters before and after the change point will give us the opportunity to evaluate the temporal trend in the future and to adjust the health care system in order to provide a health care service that meets the population needs in the future.

In the existence of significant trend, the SARIMA model is applied to the trend-free residuals of a trend model for HFr time series. This technique allows us to model the deterministic part of the seasonal fluctuation of HFr by a time trend model and to model the stochastic part by a SARIMA model. The SARIMA and time trend ARIMA model (TT-ARIMA) performances are then compared with the observed HFr time series.

Results

During 1993–2004, 22,855 hip fractures were identified in the Montreal region among which, 17,325 were females (75.80%) and 5530 were males (24.20%). Elder females (F2 group) have the highest number of hip fractures, 13,727 (60.06%), followed by the younger females (F1 group, 3598 hip fractures, 15.74%), elder males (M2 group, 3442 hip fractures, 15.06%) and the younger males (M1 group, 2088 hip fractures, 9.14%). The female to male ratio of hip fracture is 1.7 and 4.01 for the two age groups.

The mean annual hip fracture incidences for the females aged 40–74 (F1 group) and the females aged 75+ (F2 group) are 283 and 1148, respectively. In the same period, the mean annual hip fracture for male populations of aged 40–74 (M1 group) and 75+ (M2 group), is 166 and 286 respectively.

The maximum annual incidences of hip fracture are 318, 1213, 218 and 341 for F1, F2, M1 and M2 groups which have been observed in 1997, 2004, 1997 and 2004, respectively.

The mean annual HFr for F1, F2, M1 and M2 groups is 63, 1270, 41 and 626, respectively, per 100,000 person-year. The highest HFr is observed in 1997, 1996, 1997 and 1995 for F1, F2, M1 and M2 groups, when the highest HF rates are 72, 1383, 56, and 677 per 100,000 person-year, respectively. The change of the total annual HFr has been given in Fig. 2(a). Age-standardized rates of hip fractures for F1 group changed from 70.20 per 100,000 person-years (95% CI, 62.61–78.68) in 1993 to 58.64 per 100,000 person-years (95% CI, 51.98–65.91) in 2004. For F2 group, the age-standardized rates changed from 1347.29 per 100,000 person-years (95% CI, 1267.82–1429.76) in 1993 to 1183.39 per 100,000 person-years (95% CI, 1117.76–1251.89) in 2004. For M1 group, the age-standardized rates were 38.65 per 100,000 person-years (95% CI, 32.64–45.52) in 1993 and 36.80 per 100,000 person-years (95% CI, 31.35–42.92) in 2004. For the M2 group the age-standardized rates were 608.98 per 100,000 person-years (95% CI, 534.82–692.84) in 1993 and 613.41 per 100,000 person-years (95% CI, 550.11–681.99) in 2004.

The female to male ratio of hip fracture rate for age groups 40–74 and 75+ is 1.52 and 2.3, respectively.

Seasonal variation

The variation of the HFr monthly mean for females and males by age groups (F1, F2, M1 and M2) in the period of 1993 to 2004 is illustrated in Fig. 2(b). The seasonal variation of HFr is clear in this figure.

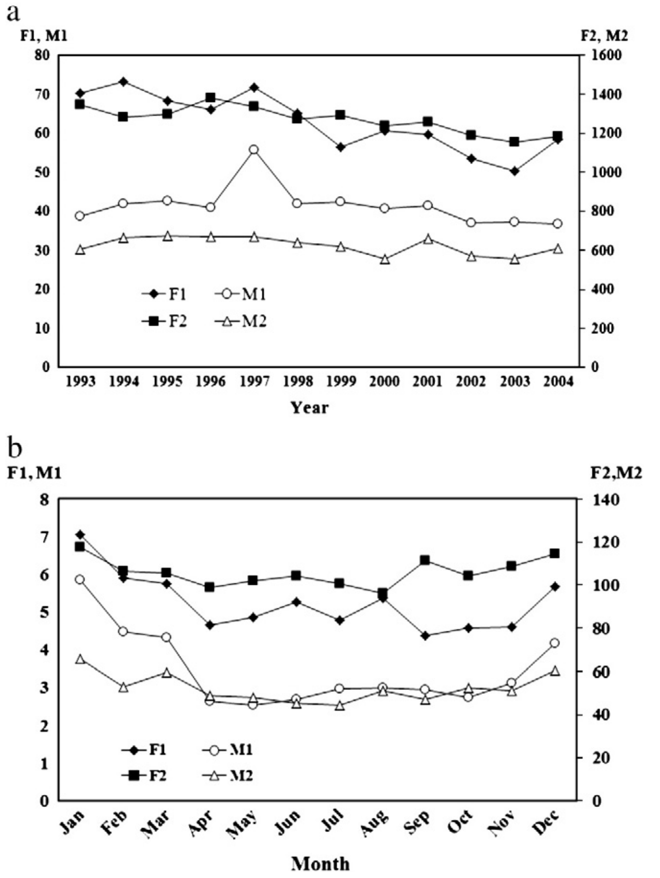

Fig. 2. The total annual HFr (a) and monthly mean of HFr (b) for different groups during 1993–2004.

Seasonal variation shows that for the male groups, the HFr begins increasing in the late autumn and continues increasing to winter time and then a decline is observed through spring and HFr remains mostly constant through summer time. The same situation is also observed for the female groups. However, the HFr shows a bit fluctuation for F1 during summer. The minimum HFr for F1 group is observed from September to November while the HFr is high for the F2 group during the autumn.

Association of hip fractures and meteorological factors

The association of climate variation and hip fractures can be investigated by using correlation coefficients (Table 1). A significant negative correlation is found between HFr of all genders and age groups and the temperature (maximum, average, minimum) ($p<0.01$). The snow depth and the number of snowy days show a positive significant correlation with HFr for all age groups and genders. The rainfall depth and the number of rainy days show a significant negative correlation with HFr. The maximum and mean wind speed seem to have no relationship with HFr while there is a negative significant correlation between the total hours of sunshine (or the length of a day) and HFr for F2, M1 and M2 groups ($p<0.01$) but the influence of the length of a day on HF of F1 group is weaker than other groups ($p<0.05$).

Trend analysis of hip fractures

For 1993–2004, the MK test for HFr data indicates a decreasing trend for F1 and F2 groups at 1% significant level and also a decreasing trend for M2 group at 5% significant level while the MK statistic is not significant for M1 group. The MK statistics are −0.257, −0.231, −0.087 and −0.119 for F1, F2, M1 and M2 groups, respectively.

Table 1
Pearson product-moment correlation coefficients between climate variables and HFr data.

Climate variables	F1	F2	M1	M2
Maximum temperature	−0.37***	−0.31***	−0.55***	−0.40***
Minimum temperature	−0.39***	−0.31***	−0.56***	−0.43***
Mean temperature	−0.38***	−0.32***	−0.58***	−0.42***
Rainfall depth	−0.28***	−0.13**	−0.42***	−0.31***
Number of days with rain	−0.42***	−0.28***	−0.54***	−0.35***
Snow depth	0.46***	0.33***	0.6***	0.34***
Number of days with snow	0.43***	0.33***	0.62***	0.42***
Precipitation depth	−0.13	0.06	−0.05	−0.14*
Number days with precipitation	−0.18**	−0.14*	−0.15*	−0.09
Maximum snow depth	0.45***	0.24***	0.57***	0.30***
Maximum wind speed	0.11	0.11	−0.03	0.00
Mean wind speed	0.07	0.01	−0.02	0.00
Hours of sunshine	−0.17**	−0.36***	−0.36***	−0.34***

* $p<0.10$.
** $p<0.05$.
*** $p<0.01$.

The changes in the number of the HFr in the period of 1993–2004 are also investigated by the Wilcoxon rank sum and Levene's tests. We need to divide the time series into two subseries before and after the change point. By applying a simple cumulative standardized test, the change point of HFr of F1, F2 and M2 groups is identified. To compare the results of Wilcoxon rank sum and Levene's test, the HFr of M1 group which does not show significant trend is also divided into two equal time series.

The results of Levene's and Wilcoxon tests for HFr are given in Table 2 and the change of the average of HFr has been given in Fig. 3. It could be seen that the mean of HFr indicates a significant (decreasing) change after the changing point identified by cumulative standardized method. The changes in the mean of HFr are significant at 1% level while the change in the mean of M2 group is significant at 5% level ($0.01<p<0.05$). The Levene's test indicates a weak change in standard deviation of F1, F2 and M2 groups which is significant at 10% level ($0.05<p<0.10$).

Time series modeling

For the HFr time series modeling, the SARIMA and TT-ARIMA models are fitted to the stationary (Trend free M1) and nonstationary (F1, F2 and M2) time series, respectively. For the F1, F2 and M2 time series which show significant trend, we fit an ARIMA model to the residuals of a polynomial time trend model of order 3 first fitted to the data with a significant trend. The SARIMA models for F1, F2, M1 and M2 groups are SARIMA(2,0,2)(2,0,2), SARIMA(0,0,2)(4,0,2), SARIMA (2,0,0)(2,0,2) and SARIMA(2,0,0)(2,0,4), respectively. The performance of these models and the TT-ARIMA models of HFr time series are illustrated in Table 3.

In terms of the general agreement between observations and model outputs, we apply two criteria. According to the coefficient of determination R^2, which describes the variance of the observed data that could be explained by the model, the performance of SARIMA

Table 2
Comparison of the mean and standard deviation of the observed subsets of HFr data by nonparametric test.

	F1		F2		M1		M2	
Period	1993–1998	1999–2004	1994–1998	1999–2004	1994–1998	1999–2004	1994–1999	2000–2004
Mean	5.7	4.7	110	101	3.6	3.2	54.2	49,3
p-value	0.001		0.001		0.130		0.014	
Standard deviation	1.58	1.14	13.5	10.8	1.68	1.18	12.7	10.2
p-value	0.056		0.099		0.221		0.072	

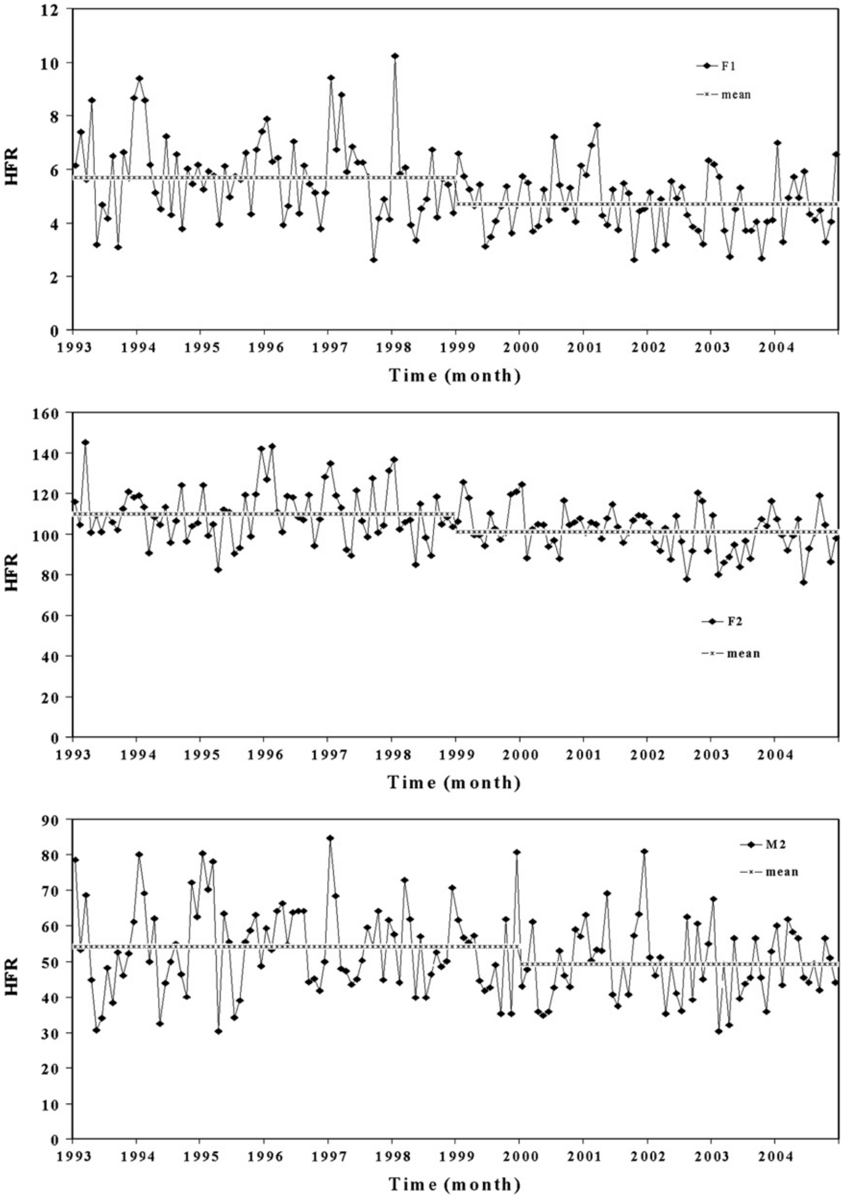

Fig. 3. The change in the mean of HFr time series of F1, F2 and M2 groups.

model for the time series with significant trend is weak (0.3, 0.31 and 0.35 for F1,F2 and M2, respectively) while the TT-ARIMA models have doubled the R^2. The index of agreement (IoAd) also shows a higher performance of TT-ARIMA model than the SARIMA model in the existence of a significant trend. In terms of the error of the model, the mean absolute error (MAE) and the root mean square error (RMSE) of the two models have also been given in this table. These two criteria also show an improved performance of a TT-ARIMA model compared with a SARIMA model if the observed time series shows a significant trend. The time series of the observed, SARIMA and TT-ARIMA estimated hip fracture time series are also given in Fig. 4. This figure also indicates a better agreement between seasonal variation of TT-ARIMA model and observed HFr time series than the agreement of SARIMA model at the presence of a significant trend. In other words, taking into account the trend of time series with a TT-ARIMA model would result in a better seasonal modeling of HFr than a pure SARIMA model.

Table 3
Multi-criteria comparison of SARIMA and TT-ARIMA models for HFr data.

Model	SARIMA				TT-ARIMA			
Criteria	R^2	MAE	RMSE	IoAd	R^2	MAE	RMSE	IoAd
F1	0.3	0.98	1.22	0.67	0.73	0.62	0.76	0.92
F2	0.31	8.23	10.75	0.68	0.84	4.03	5.13	0.95
M1	0.83	0.46	0.6	0.95	–	–	–	–
M2	0.35	7.95	9.55	0.72	0.89	3.21	3.97	0.97

Discussion

The present study represents seasonal variation modeling of four monthly gender-wise number of hip fracture age-standardized rate (HFr) time series (females and males of the ages 40–74 and 75+) of the Montreal region, Canada, in the period of 1993–2004.

It was observed that the peak of HFr for younger and older people is different. This could be related to the fact that the females and males of 75+ do not leave their home during snowy days. Although the hip fracture could happen by indoor falling, the reduction of the length of the day and night falls because of darkness could be considered as the factors controlling the HFr seasonal variation and the peaks of the occurrence during winter time [21,23].

Although the relationship between climate variables and HFr is significant, the decreasing trend of HFr cannot only be considered as the result of the change in climatic variables. The effect of other factors such as nutrition, medication, genetic causes, physical activity and hormone-therapy for women should be considered and their association with HFr reduction should be carefully investigated.

The higher percentage of hip fracture can be seen for female groups which were also reported by Levy et al. [18] for the period 1981–1992 in Quebec. Because women have more bone loss and falls more than men, their incidence of hip fracture is about twice that seen in men at any age in the USA and Europe and because women live longer than men, more than three-quarters of all hip fractures occur in women [1,19,24–26] but the risk is doubled from younger to elder women [24].

An important finding of this paper is the existence of a significant trend for three out of four HFr groups during 1993 and 2004 at the Montreal region, Canada. The HFr of F1, F2 and M2 groups show a decreasing trend while the HFr of M1 group (men of the age 40–74) does not show significant trend. These findings are consistent with findings of North America, Australian and European studies [27,1,19,25,28–30] but differ from those found by Levy et al. [18] for the period 1981–1992. Those authors did not find any statistically significant trend in the temporal changes in age-standardized hip fracture rates in Montreal. However, in another study the change of the slope of trend was observed around 1996–1997 in Ontario and Canada [25,19].

In this study, the nonparametric methods indicate a significant change in the mean value of HFr of the above three groups (F1, F2 and M2). However, the standard deviation of HFr shows a small weak reduction at 10% significant level. That means the variation of HFr around the mean value (more than or less than the mean HFr) has changed (reduced) after the change points (1999–2000).

Leslie et al. [19] found that there is no clear answer to the very important question of factors that could contribute to the decline in hip fracture rates in Canada. These authors mentioned among these factors the secular increase in the average number of reproductive years and exposure to circulating endogenous hormones reported in females and the improvements in physical activity, calcium intake, vitamin D status, or fall prevention. Declining smoking rates, the possibility of a birth cohort effect resulting in a healthier aging population with improved functional ability and reduced risk of fall injurious has also been proposed for reduction of HFr as well as the overweight and obesity epidemic in modern societies [19]. The increase in the proportion of population being treated with antiresorptive medications (biphosphonates) has been suggested by Jaglal et al. [25] in Ontario and Fisher et al. [28] in Australia.

The variation of HFr for all four groups investigated in this study shows a consistent seasonal pattern of the rate of hip fractures. The number of hip fractures is usually highest in the winter time and the lowest in summer time. The number of hip fractures decreases at the end of the winter and during the summer then starts to increase again during the autumn. However, the minimum HFr of F1 group can be seen in autumn. The same seasonal variation of HFr can also be observed. The seasonality of climatic variables which shows a significant relationship with HF and HFr for all groups could be one of the main reasons of seasonal variation of hip fracture time series. There is a negative and positive correlation between temperature and snow depth with HFr data which implies the higher rate of HFr in winter time and lower rate in summer time. The relationship of HFr with the hours of sunshine is also negative. Mirchandani et al. [21] found also a significant correlation between the average monthly hours of sunshine and the number of hip fractures in their study about the seasonality of hip fractures in elder people in New York City and related it to the different dynamic characteristics of younger and elder people who prefer to stay at home during night.

However, hours of sunshine were not significantly associated with hip fractures in Taiwan, after adjustment for trend, seasonality and month [10]. Therefore, these seasonality variations of hip fracture incidences confirm the significant role of the summer–winter seasonal difference in HFr not only in high latitude countries but in some low latitude countries such as Taiwan and Hong Kong as well [10,16,21].

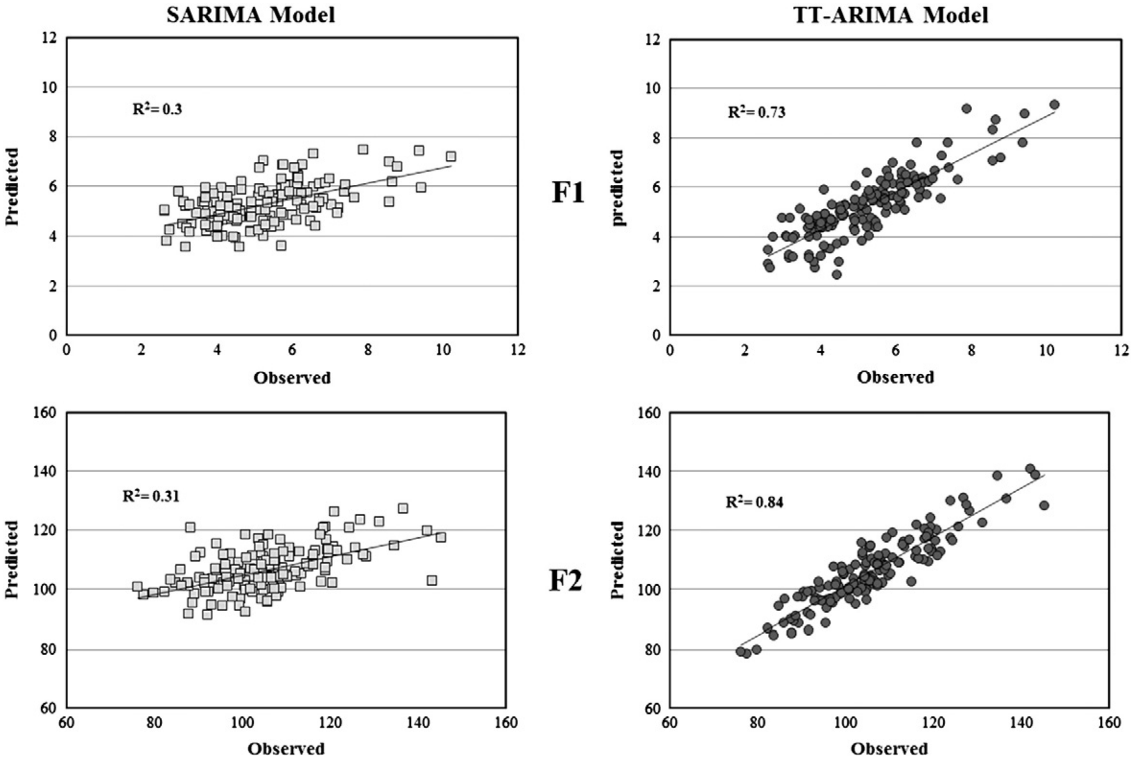

Fig. 4. Observed vs. modeled HFr time series for F1, F2, M1 and M2 groups.

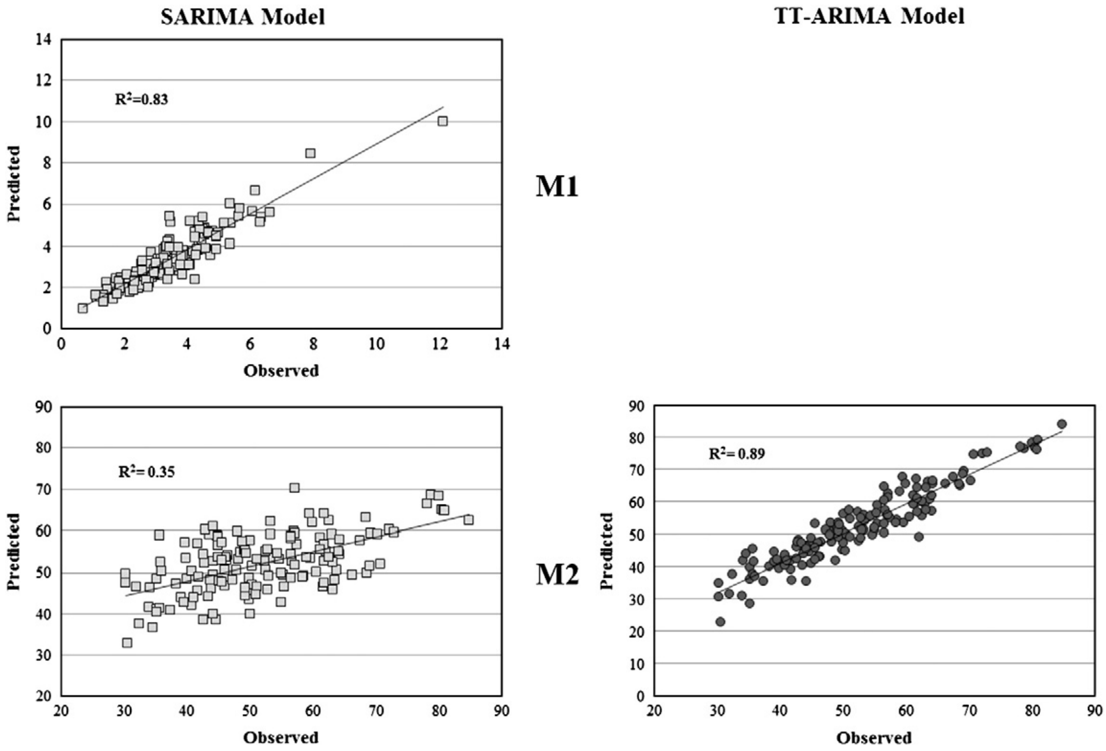

Fig. 4 (*continued*).

The most important contribution of the present study is that the existence of a trend is considered for the seasonal autoregressive integrated moving average (SARIMA) modeling of hip fracture time series. The SARIMA model fitted to F1, F2 and M2 of HFr time series seems to be inadequate to capture the trend in the observed time series while the SARIMA model fitted to HFr time series of M1 group shows a good agreement with the observed data according to the multi criteria model validation. For HFr time series with a significant trend (F1, F2 and M2 groups) the TT-ARIMA model which considered the trend of hip fracture shows a clear improvement in modeling both the seasonality of data and the existing trend. The multi criteria comparison indicates that the performance of the TT-ARIMA model is two times better than the SARIMA model and the error has been reduced to half. This type of ARIMA model is therefore strongly suggested for time series modeling of HFr with significant trend. The performance of TT-ARIMA model is better than that of an ARIMA regression analysis for hip fracture time series of Taiwan [10] although the trend analysis was not applied for hip fracture data. The time series are also useful models for forecasting. Because of the importance of HFr modeling and forecasting, as well as determining the effective factors on hip fracture incidence, an accurate modeling approach such as the TT-ARIMA model seems to be necessary in order to reduce the error of the model. This error reduction will result in a better hip fracture modeling and forecasting and also reducing the financial burden on both the government and the people. The proposed model finally will lead to a better planning and decision making for health management systems in the context of future climate change and trend.

Conclusions and further studies

Our findings on hip fracture seasonal modeling of the Montreal region show a strong seasonal variation of hip fractures in this region. However, the meteorological variables seem to be insufficient explanatory variables of hip fracture variation. We need to separate indoor and outdoor incidence data or evaluate the effects of other life-style related factors on HF incidences. It is also interesting to consider in future studies if the patients are retired or still working as retirement may reduce the mobility and therefore reduce the risk of incidence.

From modeling point of view, both the SARIMA and TT-ARIMA model used in this study are useful statistical techniques for modeling seasonal variation of HF. However, as linear models, there are some inadequacies in their performances. Therefore, the application of nonlinear and multivariate time series models with exogenous data such as climate variables is strongly recommended for hip fracture modeling. The models such as an ARMA with exogenous variable, univariate and multivariate nonlinear time series models and multiple regression models would be useful for modeling seasonal relationship of hip fractures with climatic variables and the trend of hip fracture data.

Acknowledgments

This research project was funded by the Institut national de santé publique du Québec (INSPQ) and the Institut national de la recherche scientifique-Centre Eau, Terre et Environnement (INRS-ETE), the Green Fund in the framework of Action 21 of the government of Québec's 2006–2012 Climate Change Action Plan and the Network of Centers of Excellence GEOIDE and the Fonds de Recherche en Santé du Québec (FRSQ). The authors also acknowledge the reviewers for their comment to improve the quality of the paper.

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