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Chronic exposure to volcanic environments and chronic bronchitis incidence in the Azores, Portugal

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Abstract

The village of Furnas, like other active volcanic areas in the world, exhibits high levels of hazardous gases. We aimed to investigate the existence of a possible association between chronic exposure to volcanic sulfur gases and chronic bronchitis. To investigate this, we used two populations, one exposed to active manifestations of volcanism (Furnas) and another from an area where no volcanic activity took place for over three million years (Santa Maria), both in the Azores. We used data on the incidence of chronic bronchitis among both populations (1991–2001), obtained from the records of each local health center, and population denominators from censuses carried out in 1991 and 2001, using five age-groups. We also estimated relative risks and mean annual age-standardized rates of chronic bronchitis incidence. Incidence rates were extremely higher in the volcanically active area for both sexes, and especially in the youngest groups. Accordingly, the risk of chronic bronchitis for the people living in the volcanically active area was extremely higher (males RR = 3.99; females RR = 10.74) when compared to those living in the volcanically inactive area. Comparison of chronic bronchitis incidence rates between both populations suggests an association between this disease and the chronic exposure to the volcanically active environment, with all its hazardous gases like hydrogen sulfide and sulfur dioxide. These findings may help health officials to better advice people inhabiting volcanic areas, or others with high levels of sulfur gases, on how to prevent and minimize the risks of chronic bronchitis.

Keywords: Sulfur; Gases; Epidemiology; Chronic bronchitis; Portugal; Volcanism

1. Introduction

Chronic bronchitis is a major public health problem worldwide defined as chronic or recurrent production of mucus in the lungs with the presence of persistent productive cough. These symptoms are present on most days for 3 months a year, for at least 2 successive years, with no other underlying pulmonary or cardiac disease (Siafakas et al., 1995; Heath and Mongia, 1998).

The main risk factors for chronic bronchitis are cigarette smoking, and chronic exposure to air-borne pollutants, such as occupational and environmental irritant dusts and gases (Haschek and Witschi, 1991; Fishwick et al., 1997). Many of these dusts and gases, in lethal and sub-lethal doses, may be of anthropogenic origin but may also be generated by volcanic eruptions and subsequent volcanic activity during hundreds of years. Volcanoes and volcanic manifestations, such as fumaroles and degassing soils, may release metals, and hazardous aerosols and gases such as the radioactive gas radon, carbon dioxide, hydrogen chloride, hydrogen fluoride, hydrogen sulfide (H_2S), sulfur dioxide (SO_2), and sulfuric acid (Haschek and Witschi, 1991; Delmelle and Stix, 2000; Durand et al., 2004).

Sulfur compounds may induce oxidative stress and changes in tissues of respiratory organs (Meng et al., 2003). For example, chronic exposure to H_2S, considered an extremely toxic gas, at concentrations as low as 50 ppm may cause pharyngitis and bronchitis while concentrations over 250 ppm may result in pulmonary edema

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(Williams-Jones and Rymer, 2000). Even at lower doses, chronic exposure to H_2S may be linked to noninfectious respiratory disease, as suggested by Bates et al. (2001) and Durand and Wilson (2006) in studies made in an urbanized geothermal field in Rotorua. A correlation between SO_2 and the prevalence of bronchitis in children has been found by Herbarth et al. (2001). On contact with moist membranes, SO_2 forms sulfuric acid, which is responsible for severe irritant effects on the eyes, mucous membranes, and skin. Sulfuric acid also depresses pulmonary particle clearance, the major protective mechanism in lungs (Williams-Jones and Rymer, 2000; Kikuchi, 2001; Komarnisky et al., 2003).

The present population-based retrospective cohort study tested the hypothesis that exposure to volcanic environment is associated to a higher risk in chronic bronchitis. In order to do this, we evaluated the differences in the incidence of chronic bronchitis, between 1991 and 2001, in two areas of the Azores (Portugal), one with active volcanic manifestations (Furnas) and the other with no type of volcanic activity (Santa Maria), by using medical data.

2. Methods

The Azores is a nine-island archipelago located in the North Atlantic Ocean at the triple junction of Eurasian, African and North American plates where seismic–volcanic events are common (Nunes et al., 1993; Lourenço et al., 1998). São Miguel, which is the largest island (757 km^2), has its geology dominated by the three active volcanoes of Sete Cidades, Fogo, and Furnas. Presenting fumarolic fields and hydrothermal vents (Booth et al., 1978; Cruz, 2003), and the always present "rotten egg" odor, the village of Furnas is built upon actively degassing ground inside Furnas caldera (Baxter et al., 1999), where the last eruption occurred at 1630 AD (Cole et al., 1995). Volcanic gases in this area are typically water vapor, carbon dioxide, H_2S, SO_2, with lesser amounts of other gases (Baxter et al., 1999; Ferreira and Oskarsson, 1999). This village has a population of about 1541 inhabitants (Serviço Regional de Estatística dos Açores, 2003), where the age-groups 0–14, 15–24, 25–44, 45–64, and over 64 represent 22%, 16%, 27%, 19%, and 16% of the population, respectively.

Santa Maria, which is one of the smallest islands (92 km^2), includes about 5578 inhabitants (Serviço Regional de Estatística dos Açores, 2003), and is also rural but, in contrast, has had no volcanic activity since 3 million years ago (Feraud et al., 1984). In Santa Maria, the age-groups 0–14, 15–24, 25–44, 45–64, and over 64 represent 24%, 16%, 30%, 18%, and 12% of the its population, respectively. Both populations are similar in access to medical care, socioeconomic status, economy, and home construction, but dissimilar in terms of smoking, where Furnas and Santa Maria differ since they present 25% and 44% prevalence, respectively (Peixoto, 2005). Furnas presents a higher precipitation regime (2252 mm), a higher humidity level (87%) and a lower temperature (15.1 °C) than Santa Maria (775 mm, 77%, 17.5 °C; Instituto de Meteorologia). There are no emissions of ashes in Furnas, and both areas present low intensity road traffic.

Diagnoses of chronic bronchitis reported by calendar date were used as incidence data on chronic bronchitis among the population of Furnas and of Santa Maria during the period 1991–2001, and were obtained from individual medical records of each local health center. These data corresponded to the registration of diagnosis of chronic bronchitis in individual medical records. In the case of Furnas the medical records were recorded by hand while in the case of Santa Maria they were in a computer database. For incidence rates, population denominators were estimated from censuses carried out in 1991 and 2001, using five age-groups. Rates were adjusted to age and sex, and mean annual age-standardized rates (ASR) of chronic bronchitis incidences were computed by means of the direct method on the basis of the European standard population. Relative risk (RR) estimates were used as the measure of association defined as the incidence of chronic bronchitis among individuals inhabiting Furnas (exposed) by the corresponding rate among individuals living in Santa Maria (non-exposed). In order to verify if the proportion of individuals with chronic bronchitis was the same in both populations, the χ^2-test was used and 95% confidence intervals were estimated (Petrie and Sabin, 2000). Data on individual smoking habits were not available in the medical records. Also, this study only accounts for the residents, therefore excluding tourists, seasonal population, and i(e)migrants.

3. Results

The number of cases of chronic bronchitis per year reported during the period between 1991 and 2001 in Furnas was approximately 1.5 males and 1.6 females, while in Santa Maria it was about 1.4 males and 0.5 females (Table 1).

In males, the incidence rate from 15 to 44 years old in Furnas was higher than the sum of the entire incidence rates for Santa Maria. Females presented similar behavior, with the incidence rate from 0 to 14 years old in Furnas being higher than the sum of the entire incidence rates for Santa Maria (Table 2). Among those with chronic bronchitis, the age-group showing higher incidence rates in Furnas was from 45 to 64 years old, both in males and females, while in Santa Maria the group with higher rates was above 64 years old, both in males and females. In

Table 1
Number of chronic bronchitis cases in Furnas and Santa Maria between 1991 and 2001

Number of cases per age-group	Furnas			Santa Maria		
	Males	Females	Total	Males	Females	Total
0–14	0	3	3	0	0	0
15–24	2	0	2	1	0	1
25–44	6	1	7	5	3	8
45–64	8	8	16	4	1	5
>64	1	6	7	6	2	8
Total	17	18	35	16	6	22

Table 2
Chronic bronchitis incidence rates (per 100,000) per age-groups, and age-standardized incidence rates (ASR), in males and females from Furnas and Santa Maria, between 1991 and 2001

	Age-group					ASR
	0–14	15–24	25–44	45–64	>64	
Furnas						
Males	0	139.9	242.4	508.6	92.8	224.8
Females	159.0	0	43.0	444.8	348.5	196.7
Santa Maria						
Males	0	19.0	52.6	71.7	190.4	56.3
Females	0	0	32.6	16.4	46.0	18.3

Table 3
Relative risk (RR) estimates, in five age-groups, and 95% confidence intervals (CI), for the relation of active volcanic environment exposure (Furnas) and chronic bronchitis, with individuals from non-active volcanic environment as reference group

Age-group	Males		Females	
	RR	95% CI	RR	95% CI
0–14	[a]		∞	
15–24	7.35	4.56–11.87	[a]	
25–44	4.61	3.42–6.20	1.32	0.84–2.08
45–64	7.09	5.54–9.08	27.14	16.58–44.43
>64	0.49	0.38–0.62	7.57	5.57–10.30
All	3.99	2.98–5.35	10.74	6.55–17.34

[a]Absence of cases in both areas; ∞—absence of cases in Santa Maria.

Furnas, chronic bronchitis affected more young individuals, aged from 0 to 14 and from 15 to 24, than in Santa Maria. Males from 15 to 24, 25 to 44, and 45 to 64 years old living in Furnas presented a higher increased risk of chronic bronchitis when compared to those living in Santa Maria. Females from 0 to 14 years old living in Furnas presented an extremely higher risk of chronic bronchitis due to the absence of cases in Santa Maria, and those from 25 to 44, 45 to 64 and over 64 also showed high increased risk of chronic bronchitis when compared to females that live in Santa Maria (Table 3).

In the period between 1991 and 2001, the estimated age-standardized incidence rates for chronic bronchitis in Furnas were higher than in Santa Maria, for males and females, as shown in Table 2. In both sexes, the RR of chronic bronchitis in Furnas were significantly higher than in Santa Maria, being about fourfold and tenfold higher in males and females, respectively (Table 3).

4. Discussion

The present paper describes and analyses the differences in chronic bronchitis incidence rates in two populations of the Azores archipelago, one inhabiting an area with active volcanic manifestations (Furnas), such as SO_2 and H_2S emanations, and the other inhabiting an area with no type of active volcanism (Santa Maria). The present study suggests an association between volcanic environmental gases and chronic bronchitis. Despite the fact that it did not include individual exposure data, the probability of misclassification of exposure to hazardous gases, such as SO_2 and H_2S, is very low given the differences between the two areas in volcanic manifestations. According to Ferreira et al. (2005), there are no reported gas emanations in Santa Maria.

In this study, the age-group showing higher incidence rates for chronic bronchitis in Furnas was from 45 to 64 years old, while in Santa Maria was the group of over 64 years old. For the youngest groups, the former also presented higher rates than the latter, what means that in Furnas, which is the volcanic active area, individuals develop this chronic disease earlier than in Santa Maria, and that perhaps an environmental cause may be affecting this occurrence. Identical to what happens in the United States of America and in the United Kingdom (American Lung Association, 2005; British Thoracic Society, 2001; National Heart, Lung, and Blood Institute, 2003), the most affected group in Santa Maria was the one over 64 years old, both in males and females. In general, Furnas presented much higher ASR of chronic bronchitis than Santa Maria, in both sexes, representing for individuals, especially middle-aged people and youngsters, living in the former an extremely higher increased risk of chronic bronchitis when compared to those living in the latter. The incidence rate of chronic bronchitis for countries with established market economies is 84 per 100,000 (Loddenkemper et al., 2003), which is higher than the ASR for Santa Maria but much lower than the one for Furnas. Since the prevalence of smoking in Santa Maria is about twice the one of Furnas (Peixoto, 2005), and the risk of cancer of respiratory and intrathoracic organs is higher in Santa Maria (Amaral et al., 2006), it is reasonable to infer that the most referred cause (tobacco) for chronic bronchitis may not be the only factor affecting the very high incidence rates of this chronic disease in Furnas.

Durand et al. (2004) verified that after 20 min of exposure of humans to volcanic gases, the levels of SO_2 were above the short-term limits for occupational exposures set by the National Institute of Occupational Safety of Health of the United States of America. The European Union establishes a 1-h limit of 0.134 ppm, that should not be exceeded more than 24 times in a calendar year, a 24-h limit of 0.048 ppm not to be exceeded more than three times in a calendar year, and an annually limit of 0.008 ppm (European Council, 1999). Baxter et al. (1999) found SO_2 at average levels of 0.01 ppm in the backyards of a couple of houses in the center of the village of Furnas, 0.08 and 0.12 ppm around the perimeter and in some of the fumaroles, respectively, during 2 weeks. Because of its high solubility, SO_2 irritates primarily the upper airway. The nasal mucosa effectively removes most inspired SO_2 during breathing at rest, but deep penetration to the lung mucosa can occur during moderate exercise, such as walking, and one of the physiologic responses to SO_2 exposure is mild bronchial constriction (Komarnisky et al., 2003; Wigington, 2002). While in Santa Maria humidity is low and there are no active volcanic manifestations, in Furnas humidity is higher and volcanic gas emissions are very common, even inside many of the houses, making easier for respiratory tissues to soak up hazardous gases. Since the atmosphere in Furnas is more humid, the possible transformation of SO_2 into sulfuric acid should also be considered as a factor depressing the integrity of the lungs (Kikuchi, 2001; Komarniski, 2003), and probably facilitating the incidence of chronic bronchitis. Herbarth et al. (2001) established a correlation between SO_2 and the prevalence of bronchitis in children. Ferreira and Oskarsson (1999) measured H_2S in fumaroles and in a river of Furnas, during several months,

at levels well above 50 ppm, which is the threshold for causing pharyngitis and bronchitis. Then, the ambient air levels of these two sulfur compounds in Furnas were close or above permitted limits at which health hazards may occur, especially in the case of H_2S (Herbarth et al., 2001; NIOSH/OSHA, 1983). A high increased risk of chronic obstructive pulmonary disease and its associated conditions have been found in clusters spatially coincident with a geothermal field in Rotorua, where the concentrations of H_2S are in the parts per billion to parts per million range, and chronic exposure of inhabitants to this gas occurs (Durand and Scott, 2005). Even though gas chemistry and individual exposure in Furnas is not known as it could be, which is also the case in all few previous studies of this sort in other regions of the world, and despite the size of the study population it is suggested that the much higher rates of chronic bronchitis in Furnas may be partially associated with chronic exposure, in a very humid atmosphere, to environmental factors resulting from volcanic activity, such as hazardous gases H_2S and SO_2.

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