

# Impact on the Respiratory Airways of Acute Exposure to Volcanic Ash in the Patagonia: Cross-Sectional Study

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## Abstract

**History:** People exposed to volcanic ash show increased respiratory symptoms. The duration of exposure, the characteristics and ash concentration are determinants of the impact on respiratory health.

**Objectives:** To describe the prevalence of wheezing over the past year within the adult population exposed to volcanic ash spilling in two cities with different levels of exposure. Secondly, to describe the prevalence of ocular and respiratory symptoms in those populations.

**Materials and methods:** A cross-sectional study was conducted five days after the eruption of the Calbuco volcano in two Patagonian cities with different levels of exposure (high and low levels of exposure). The prevalence of wheezing and respiratory and ocular symptoms was evaluated by means of telephone surveys conducted through an interactive voice response system.

**Results:** The prevalence of wheezing was similar both in cities with low and with high levels of exposure (30.2% vs. 31.0%;  $p$ : 0.82). The respiratory and ocular symptoms were 32% and 57%, respectively ( $p$ : NS).

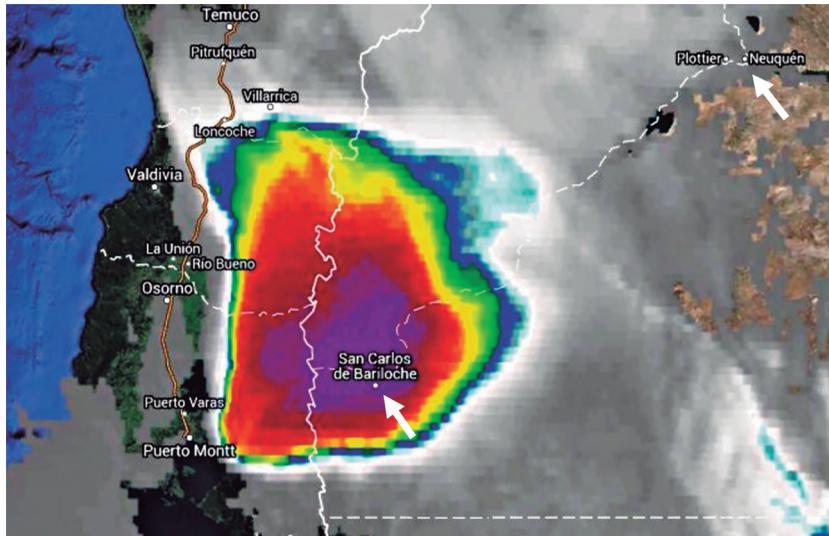
**Conclusion:** After the eruption of the Calbuco volcano, a high proportion of the exposed population showed wheezing and respiratory and ocular symptoms. No differences were shown between the analyzed cities. The prevalence of wheezing in these cities was higher than that reported on the national level. The respiratory symptoms and the prevalence of wheezing in adults were higher than those reported on the national level.

**Key words:** Volcanic ash, Respiratory health, Symptoms, Asthma

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## Introduction

9% of the world's human population living near active volcanoes knows and accepts the consequences of eruptions<sup>1</sup>. The amount of people that may be affected by ashes produced during volcanic eruptive events is not limited to population living nearby, given the natural dispersion and cyclic suspension of volcanic material by the action of the wind and human activity<sup>2</sup>. Therefore, it is very important to know the potential adverse health effects derived from volcanic activity in order to determine actions and strategies to face sanitary problems caused by volcanoes within the exposed population. Globally speaking, Indonesia reports the highest number of deaths related to historical eruptions (~61%), and the third place (~9.5%) goes to South America<sup>3</sup>. The Andean Mountains contain 66 of the 550 active volcanoes worldwide, and are given third place regarding the frequency of volcanoes with registered eruptions at least once, after Indonesia and Japan. Recently, two volcanic events were produced in the region of the Chilean Patagonia, Puyehue-Cordón Caulle (2011) and Calbuco (2015). In both cases, ash dispersion affected the same area of the Argentinean Patagonia (**Figure 1**), causing socio-economic and health-related problems for the population<sup>4, 5</sup>.



**Figure 1.** Satellite image of the eruption of the Calbuco volcano. The two surveyed cities can be observed (dates): San Carlos de Bariloche and Neuquén. Source: National Geology and Mining Service, Ministry of Mining, Chile ([www.sernageomin.cl/](http://www.sernageomin.cl/)).

Acute exposure to suspended volcanic ashes causes ocular and respiratory symptoms, mainly due to the inflammatory response to inorganic particles<sup>6, 7</sup>. Previous studies of other eruptive events reported a higher rate of respiratory symptoms and exacerbations of chronic respiratory diseases in the adult population exposed to these ashes. The same was reported for Bariloche, with the eruption of the Puyehue-Caulle mountain range in 2011<sup>8-10</sup>.

In 2013, two years after the eruption of the Puyehue-Caulle mountain range, our team, using the ISAAC methodology<sup>11</sup> (International Study of Asthma and Allergies in Childhood), reported 14% prevalence of asthma-related symptoms in 13 and 14 year old school-attending students exposed to volcanic ashes in the city of Bariloche. This figure exceeded the known historic figures for these symptoms in this city<sup>12</sup>. However, lung function results measured by spirometry were not affected in this population. The same was reported by *Benitez et al* regarding the adult population affected by the same volcano<sup>10</sup>. The eruption of the Calbuco volcano provided a unique opportunity to describe the short-term impact on the prevalence of symptoms comparing two populations with different levels of acute exposure to ashes.

The primary objective of this study is to explore the prevalence of wheezing five days after the eruption within the adult population of two cities with different levels of exposure to volcanic ash. Secondly, to evaluate the prevalence of ocular and general respiratory symptoms in those populations.

## Materials and Methods

We developed a cross-sectional, population-based study five days after the eruption of the Calbuco volcano (April 30, 2015), to compare two cities of the northwestern area of the Argentinian Patagonia. Since the air quality measurement was not available when the study was published, the level of exposure was determined according to the distance from the Calbuco volcano to each city (41.3304° S, 72.6087° W). The city of San Carlos de Bariloche (41.1335° S, 71.3103° W) is located 70 km from the focus. Given that ash accumulation was evident and visible, this city was defined as a high-level exposure environment. On the other hand, the city of Neuquén, located 500 km from the eruption (38.9517° S, 68.0592° W) showed weak ash spilling and so was defined as a low-level exposure area (**Figure 1**).

The subjects were recruited through simple randomization, using a database of landlines (not mobiles) of the urban area of both cities. Each subject received a call through the Interactive Voice Response system (IVR) and answered a questionnaire of 19 structured questions. We used previously validated

and reported questions from the International Study of Asthma and Allergies in Childhood (ISAAC).<sup>12</sup> The protocol considered individuals older than 18 years old, capable of using the IVR system, as eligible subjects, and prohibited a second call to the same telephone number. We defined the “complete case” as the subject who completed the questionnaire; incomplete cases were not included in this analysis. Also, the system concluded automatically after obtaining the sample size.

The main variable under evaluation was the presence of wheezing or chest whistling over the last 12 months. The secondary variables explored the following: a) global respiratory symptoms (thoracic wheezing, cough or phlegm), b) ocular symptoms (ocular pain or tearing), c) perception of health risks associated with the volcanic event (medical consultation for the symptoms, information regarding the ashes, taking preventive measures, consequences of exposure for health and respiratory health) and d) perception of the level of exposure to ashes. Demographic data were evaluated: gender, age, level of education attained, health insurance, perception of current health status of the interviewed subject (very good, good, bad, very bad or doesn't know) and active smoking (¿do you currently smoke?). These last questions were designed based on previous questionnaires used in pilot studies.

Sample size was calculated based on previous reports on wheezing prevalence over the past year within the exposed population in comparison with the general non-exposed population (26% vs. 10.2%, respectively); with 210 subjects in each group<sup>13</sup>. We applied a two-tailed test with 80% power and 95% significance level.

The analysis was made by means of the STATA (® Texas, USA) statistical package, using proportions to characterize the population and describe the prevalence of wheezing, global respiratory symptoms, ocular symptoms and other secondary results. Taking into account the distribution and objectives, we used the chi square, Wilcoxon and T tests. Results were reported with 95% confidence intervals, and the p value below 0.05 was considered as significant in the two-tailed analysis.

*Ethical approval:* This study has been approved by the Ethics Committee of the Ramón Carrillo Regional Hospital, in the city of Bariloche.

## Results

2500 telephone numbers were dialed and 819 complete surveys (32.7%) were obtained. 420 subjects were surveyed in the city of Neuquén and 399 in the city of Bariloche. The mean age of the general sample was  $48.8 \pm 17.7$  years. The population of Bariloche was slightly larger than that of Neuquén. There were more female subjects (67.8%) and active smoking was similar to the general prevalence of the Argentinian population (23.3%). The other demographic data are shown in **Table 1**.

The prevalence of wheezing over the past 12 months was 30.6%, with no statistically significant differences between the city of Neuquén and Bariloche, 30.2% vs. 31.0%, respectively. As shown in **Figure 2**, we observed high prevalence of post-eruptive respiratory and ocular symptoms; there was also high prevalence of information gathering by the population about the consequences of volcanic ashes for health.

The self-report about exposure to volcanic ash showed high-level exposure in both cities; nevertheless, the population of Bariloche had higher prevalence of the use of preventive measures and of the perception of suspended ashes, in comparison with the information provided by the population of Neuquén. Other self-perception variables about exposure and symptoms within the surveyed populations are detailed in **Table 2**.

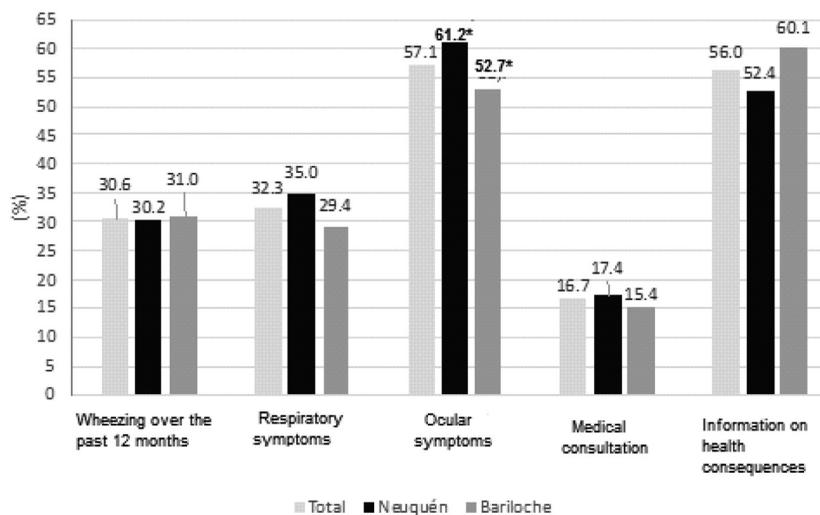
## Discussion

This study was the first research work exploring the sanitary and social impact of the Calbuco volcano eruption. The importance of the results was that the population was able to recognize the prevalence of symptoms and perceive health risks during acute exposure to volcanic ashes. Locally, the information about the health impact after every volcanic eruption is limited: all the reported data were subsequent to the eruption of the Puyehue-Caulle mountain range in 2011<sup>10,11</sup>. The main result we observed was the high prevalence of wheezing over the past 12 months in the overall sample under evaluation, without a

**TABLE 1.** Demographic information stratified by city

	Total (n: 819) n (%)	Neuquén (n: 420) % (95IC)	Bariloche (n: 399) % (95IC)
Age mean ( $\pm$ SD)	48.7 ( $\pm$ 17.7)	47.1 ( $\pm$ 17.4)*	50.5 ( $\pm$ 17.8)*
Gender			
Male	252 (32.1)	31.5 (27.1-36.2)	32.7 (28.1-37.6)
Female	533 (67.9)	68.5 (63.7-72.8)	67.2 (62.3-71.8)
Level of education			
Primary	84 (10.39)	7.3 (5.1-10.3) <sup>λ</sup>	12.5 (9.5-15.2) <sup>λ</sup>
Secondary	322 (39.7)	39.4 (34.3-43.9)	40.7 (35.8-45.7)
Tertiary/University	405 (50.0)	53.6 (48.7-58.5) <sup>§</sup>	46.8 (41.8-51.9) <sup>§</sup>
Health insurance			
Through mutual assistance association	389 (47.6)	57.6 (52.8-62.3) <sup>λ</sup>	37.0 (32.4-41.9) <sup>λ</sup>
Private	158 (19.3)	13.3 (10.4-16.9) <sup>§</sup>	25.7 (21.6-30.2) <sup>§</sup>
Retirement plans	132 (16.2)	12.1 (9.3-15.6) <sup>λ</sup>	20.4 (16.7-24.6) <sup>λ</sup>
No insurance	138 (16.9)	16.9 (13.6-20.8)	16.9 (13.4-20.9)
Health status perception			
Doesn't know	40 (4.9)	4.0 (2.4-6.4)	5.8 (3.0-7.5)
Very good	243 (29.7)	31.4 (27.3-36.4)	27.9 (23.9-33.0)
Good	459 (56.1)	56.7 (52.2-62.0)	55.5 (50.8-60.8)
Bad	63 (7.7)	6.9 (4.1-8.9)	8.5 (6.3-12.1)
Very bad	13 (1.6)	0.9 (0.4-2.6)	2.3 (1.2-37.4)
Active smokin			
Yes	189 (23.3)	22.4 (18.5-26.8)	25.0 (20.9-29.6)
No	621 (76.7)	77.6 (73.2-81.4)	75.0 (70.4-79.1)

CI95: 95% Confidence Interval.  $\lambda$ :  $p \leq .05$   $\S$ :  $p < .01$  \* $p < .001$



\* $p < 0.0$

**Figure 2.** Ocular and respiratory symptoms, medical consultations, and information on health consequences stratified by city.

**TABLE 2.** Descriptive information on the questionnaire about perception of the risks of respiratory disease, stratified by city

	Total (n: 819) n (%)	Neuquén (n: 420) % (95IC)	Bariloche (n: 399) % (95IC)	p
Exposure to ashes	686 (84.1)	86.5 (82.8-89.5)	81.8 (77.6-85.3)	0.09
Ashes suspended in the air.	704 (86.1)	83.8 (79.6-86.9)	88.5 (28.1-37.6)	0.05
Health consequences	688 (84.1)	85.3 (81.2-88.2)	84.3 (80.4-87.6)	0.89
Period during which the ashes affect the lungs				
Short-term	173 (21.1)	22.4 (18.6-26.8)	20.2 (16.5-24.5)	0.38
Medium-term	359 (43.8)	46.6 (41.8-51.5)	40.5 (35.7-45.5)	0.29
Long-term	254 (31.0)	27.7 (23.5-32.2)	34.6 (30.0-39.5)	0.95
Do not affect the lungs	33 (4.0)	3.2 (1.9-5.5)	4.6 (2.9-7.2)	0.60
Respiratory health consequences	210 (26.4)	29.9 (25.6-34.6)	23.1 (19.1-27.5)	0.06
Use of preventive measures	544 (66.6)	59.1 (54.2-63.8)	75.1 (70.6-79.1)	< 0.01

Affirmative answers to questions asked. 95CI: 95% Confidence Interval. We used the Pearson's chi square Test.

statistical difference between the two cities This result was similar to the data reported by *Carlsen et al.*, which showed in a population-based study 43% prevalence of respiratory symptoms within the population exposed to the ashes of the Eyjafjallajökull volcano, with no correlation with the lung function.<sup>14</sup> One week before the development of our study, the National Survey about the Prevalence of Asthma in the Adult Population in Argentina was conducted, and reported 13.9% prevalence of wheezing over the past 12 months. The survey used a similar technology and primary variable<sup>15</sup>. The comparison between the results of both studies showed a significant difference in wheezing prevalence over the past year between exposed and unaffected areas. This difference could be explained by exposure to volcanic ash.

We found high prevalence of post-eruptive respiratory and ocular symptoms and high perception of exposure, suspended ash and health risk. However, it is interesting to observe that the rate of medical consultations for these symptoms was low in both cities. These explored variables must be analyzed carefully, bearing in mind that all of them have some degree of bias determined by exposure; we believe these may be facilitators of sanitary decisions in the affected areas.

In the city of Bariloche, as compared with Neuquén, more preventive measures were taken and more information gathering was reported about the consequences of volcanic ashes for health. These results could influence those obtained from the primary variable. The lower prevalence of ocular symptoms in Bariloche compared with Neuquén could be related to the application of these preventive measures, as for example, using barrier techniques when the exposure is inevitable and not exposing oneself whenever possible. Therefore, we consider the dissemination of preventive measures as extremely important to prevent associated symptoms.

Our study has limitations; it was possible to design it within the framework of an abrupt environmental event, and it does not allow us to draw causal conclusions between the exposure and the disease. The "Healthy worker bias" effect could influence our result. Facing these events, subjects with chronic conditions that could potentially be affected take extraordinary measures and avoid exposure. On the other hand, the lack of information about air particle concentration in both towns causes an important gap in the interpretation of the results of reported symptoms. This can be explained by the deficit of environmental air quality meters provided by government organisms. Even with these devices in both cities, data gathering was and is until today a difficult task<sup>16,17</sup>. We believe it is truly important to have this information, and it is necessary to have permanent air monitoring stations. This kind of measurements are common in other cities potentially exposed to these events<sup>7,18</sup>.

This study has been designed and developed during the ash spill, a period of acute exposure, and we could not obtain the necessary economic support to create a more adequate study. The positive aspect of these results is their acceptable external validation at population level; the reported prevalence of smoking was similar to that of the Argentinian population<sup>19</sup>. We believe that the results could have been overestimated and limited for determining if volcanic ash is a risk factor for the exacerbation of chronic respiratory disease. But fortunately, the data showed that the exposed population was well informed and took preventive measures to prevent health problems. This difference could justify the fact that there wasn't a discrepancy between populations regarding respiratory symptoms.

A better understanding of the respiratory effects that occurred after the eruption of the Calbuco volcano is necessary. For that reason, we encourage a more thorough scientific research on the health status following these events, in order to contribute to the determination of the interaction between volcanic particles and human beings.

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**Conflicts of interest:** The authors declare there is no conflict of interest.

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