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Relationship between meteorological conditions and respiratory syncytial virus in a tropical country

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SUMMARY

This study aimed to determine which meteorological conditions are associated with respiratory syncytial virus (RSV) isolates in a population of children hospitalized with acute lower respiratory infection (ALRI) in Bogota, Colombia. In an analytical cross-sectional study, links were examined between the number of monthly RSV infections and monthly average climatic variation (temperature, relative humidity, rainfall, wind speed, solar radiation) between 1 January 2010 and 30 April 2011 in a population of hospitalized children aged <3 years with ALRI caused by RSV. Out of a total of 1548 children included in the study (mean age 9·2 ± 8·5 months), 1194 (77·1%) presented RSV infection during the 3-month period from March to May. In the multivariate analysis, after controlling for wind speed, relative humidity, and solar radiation, monthly average temperature [incident rate ratio (IRR) 3·14, 95% confidence interval (CI) 1·56–6·30, $P = 0{\cdot}001$] and rainfall (IRR 1·008, 95% CI 1·00–1·01, $P = 0{\cdot}048$) were independently associated with the monthly number of RSV infections. In conclusion, in Bogota, a tropical Latin American city, average temperature and rainfall are the meteorological variables most strongly associated with RSV isolation in children hospitalized with ALRI in the city.

Key words: Children, climatic factors, epidemic, respiratory syncytial virus.

INTRODUCTION

Acute lower respiratory infection (ALRI) is acknowledged as one of the leading causes of morbidity and mortality in children aged <5 years worldwide [1]. Although ALRI represents a significant proportion of diseases in high-income countries, it is an even greater health problem in low- and middle-income countries (LMIC) [2]. The problem is of such magnitude that ALRI has been considered by far the major cause of death in children living in LMIC [2–4]. Respiratory syncytial virus (RSV) is recognized as being one of the most important causes of ALRI in infants and young children throughout the world [5]. It is important to note that the overwhelming majority of these infections occurs in LMIC [3]. There is compelling evidence suggesting a link between certain meteorological parameters and RSV activity in the

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community; this information may be useful in understanding the epidemiology of this virus, in predicting epidemics, and in planning preventive measures to target high-risk populations during high-occurrence periods of RSV activity. The latter could be achieved by administrating passive immunization with specific RSV antibodies in infants in a more cost-effective manner, or in the cohorting of infants with respiratory illnesses in hospitals as a strategy for limiting the spread of RSV. In this regard, prior studies have already suggested that RSV infections may have unique characteristics in countries located in tropical areas: in contrast to temperate climates, where outbreaks of RSV occur during the autumn, winter, and/or spring months, in equatorial zones and in other tropical climate areas, RSV infections have been shown to be clearly associated with the rainy season [6]. Furthermore, relative air humidity and surface ultraviolet B (UVB) radiation have also been shown to be associated with RSV activity in these equatorial zones [7]. However, although the peak of RSV infections occurs in the rainy season, RSV can be isolated throughout the entire year in tropical countries [8], suggesting that our knowledge of the association between meteorological conditions and the activity of RSV in these countries may be incomplete. In addition, only a limited amount of information regarding this association between meteorological conditions and RSV epidemic activity is available for tropical LMIC, where the problem is greater still.

The aim of this study was to assess monthly RSV activity in relation to meteorological parameters, and to determine which meteorological conditions are linked to RSV isolates in a population of children hospitalized with ALRI in Bogota, Colombia, a tropical LMIC.

MATERIALS AND METHODS

Study site

The geographical and meteorological conditions of Bogota, the Colombian capital, have been described in a previous study published by our group [8]. In brief, the city is located at an elevation of about 2650 m above sea level, on a mountain-rimmed plateau high in the Andes Mountains, lying only 4° 36′ north of the equator. Although temperatures are relatively consistent throughout the year, weather conditions can change markedly from one hour to the next. The mean annual temperature of the city is 14·5 °C, with variations during the day ranging between 6 °C and 19 °C on cloudless days, and between 10 °C and 18 °C on extremely rainy days. The warmest month is March, with a maximum temperature of 19·7 °C. The coldest nights occur in January, with an average of 7·6 °C in the city; fog usually occurs in the early morning, 220 days per year, while sunny days are quite unusual in the city [9]. The mean annual relative humidity is 79% and mean monthly relative humidity ranges from 76% in February to 83% in November. Mean annual rainfall in the city is about 672 mm and the mean annual wind speed is 1·5 m/s. The city typically has alternating rainy and dry seasons right throughout the year, with the dry season running from December to March and from June to August, and the rainy season running from around March to May and from September to November [10, 11]. The Fundacion Hospital La Misericordia is a tertiary-care university-based children's hospital located in the metropolitan area of Bogota. The hospital has 287 beds, and functions as a referral centre for the city of Bogota (7 363 782 inhabitants) admitting around 12 000 children, and receiving more than 60 000 emergency room visits per year.

Study design and procedures

In an analytical cross-sectional study, we examined a consecutive sample of children aged <3 years with ALRI who were hospitalized at the Fundación Hospital La Misericordia between 1 January 2010 and 30 April 2011. After collecting demographic and clinical data, all patients underwent nasopharyngeal aspirate (NPA) testing for RSV. NPA for virus detection was taken immediately upon admission to the emergency department or within 48 h of admission using a standardized technique, and was immediately processed or stored at 4 °C until the next working day (in a phosphate-buffered saline transport medium at 2–8 °C for 24 h or at 70 °C for >24 h). Those children screened were tested for RSV antigen using a rapid immunoassay method (Abbott Test Pack RSV Rapid Diagnostic kit; Abbott, USA). During the monitoring period, data were added on a monthly basis in order to estimate the number of RSV infections for each calendar month.

Ethical standards

The authors assert that all procedures contributing to this work comply with the ethical standards of the relevant national and institutional committees on human experimentation and with the Helsinki Declaration of 1975, as revised in 2008. The study protocol was approved by the Local Ethics Committee.

Table 1. *Number of monthly respiratory syncytial virus (RSV) infections, and monthly variation of rainfall, temperature, relative humidity, wind speed, and solar radiation*

	No. of RSV infections	Rainfall (mm)	Temp. (°C)	Relative humidity (%)	Wind speed (m/s)	Solar radiation (W/m^2)
2010						
January	54	14·03	14·66	59·29	1·99	216·61
February	52	31·35	15·56	63·74	1·97	203·47
March	174	27·13	15·53	64·60	1·86	181·82
April	251	206·03	15·04	72·67	1·53	149·82
May	174	216·68	15·10	72·19	1·63	142·09
June	93	94·87	14·46	69·55	1·75	151·75
July	28	167·79	13·96	69·85	1·58	148·68
August	29	40·91	13·93	66·39	1·89	157·21
September	21	74·63	13·89	68·24	1·52	149·04
October	14	196·61	14·07	68·64	1·69	154·08
November	10	251·73	13·83	73·89	1·44	125·16
December	15	147·94	13·58	69·78	1·49	140·95
2011						
January	18	92·12	13·88	65·39	1·69	203·16
February	20	110·91	14·11	67·26	1·76	165·99
March	162	153·79	14·03	68·39	1·75	154·01
April	263	246·54	14·34	70·63	1·62	152·01
May	170	156·44	14·73	67·95	1·79	141·79

Meteorological data

Temperature (°C), relative humidity (%), rainfall (mm), wind speed (m/s), and solar radiation (W/m^2) were routinely measured at Bogota's Air Quality Network (BAQN), which consists of 14 stations distributed throughout the city that have been monitoring meteorological parameters since 1997 [12]. These data were available on a daily basis from 1 January 2010 to 30 April 2011, and for each meteorological variable, a monthly average was calculated.

Statistical analysis

Continuous variables are presented as mean±standard deviation (S.D.) or median (interquartile range), whichever is appropriate. Categorical variables are given as numbers (percentage).

The bivariate correlation between the number of monthly RSV infections and meteorological variables was analysed using Spearman's rank correlation coefficient. To identify predictor meteorological variables independently linked to the number of monthly RSV infections, we used a negative binomial regression to allow for overdispersion in the distribution of the number of monthly RSV infections. This regression technique, which can be considered to be a generalization of Poisson regression, can be used for overdispersed count data, because it has the same structure as Poisson regression and it has an extra parameter to model the overdispersion [13]. Regression results are reported as incident rate ratios (IRR) and their respective 95% confidence intervals (CI). All statistical tests were two-tailed, and the significance level used was $P < 0{\cdot}05$. The data were analysed with Stata v. 11·0 software (Stata Corporation, USA).

RESULTS

Study population

Of the 3931 samples collected of children with an ALRI diagnosis during the study period, 1548 (39·4%) that tested positive for RSV were selected for inclusion in the study. The mean (±S.D.) age of the patients included in the analysis was 9·2 ± 8·5 months.

Overview of monthly RSV activity and meteorological parameters

Monthly number of RSV infections, along with monthly variation of rainfall, temperature, relative humidity, wind speed, and solar radiation are given in Table 1 and illustrated in Figure 1. Upon analysing the RSV activity monthly distribution data, it became clear that, although RSV activity was continuous throughout the

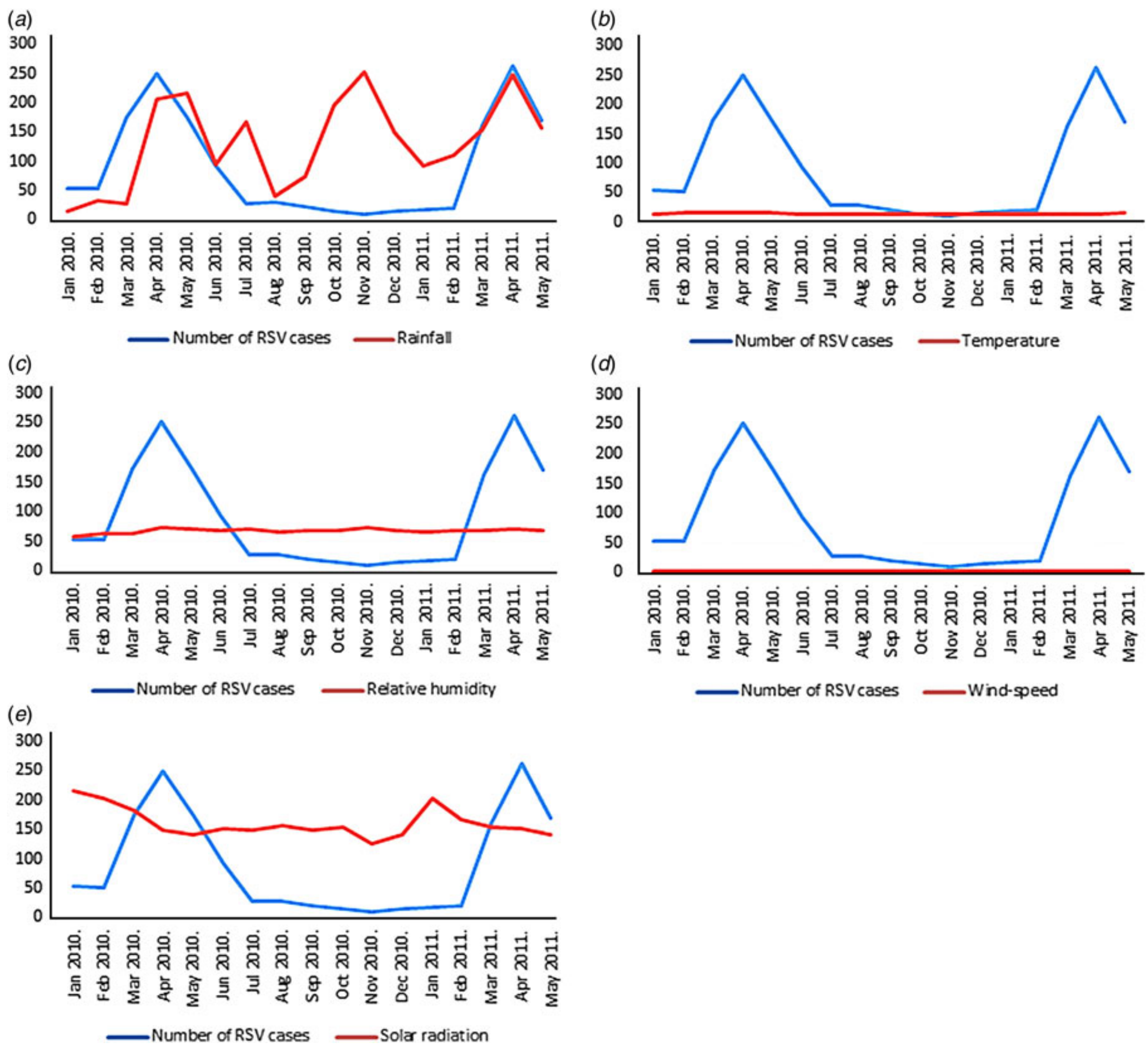

Fig. 1. Monthly number of respiratory syncytial virus (RSV) infections, and monthly variation of (*a*) rainfall, (*b*) temperature, (*c*) relative humidity, (*d*) wind speed, and (*e*) solar radiation. The x-axis shows the date (covering the period from January 2010 to May 2011). The y-axis shows the monthly number of RSV infections and the average monthly rainfall, temperature, relative humidity, wind speed, and solar radiation.

study period, there was a definite and abrupt increase in the absolute number of positive RSV cases during the 3-month period from March to May, the first rainy season of the year in the city (Fig. 1).

Association between meteorological features and RSV activity

As mentioned above, the association between the number of monthly RSV infections and the meteorological variables (temperature, relative humidity, rainfall, wind speed, solar radiation) was analysed using bivariate and multivariate analyses. In the bivariate analysis, the number of monthly RSV infections was positively and significantly correlated with temperature (Spearman's $\rho = 0{\cdot}730$, $P < 0{\cdot}01$). No other variable was significantly correlated with the number of monthly RSV infections in the bivariate analysis (Table 2). In the multivariate analysis, after controlling for wind speed, relative humidity, and solar radiation, temperature (IRR 3·14, 95% CI 1·56–6·30, $P = 0{\cdot}001$), and rainfall (IRR 1·008, 95% CI 1·00–1·01, $P = 0{\cdot}048$) were independently linked to the number of monthly RSV infections (Table 3). The proportion of variance of the outcome variable explained by the predictors was 8·5% (pseudo-$R^2 = 0{\cdot}0851$). However, the model constructed simultaneously used rainfall and relative humidity, and these two variables showed a strong

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Table 2. *Correlations between the number of monthly respiratory syncytial virus (RSV) infections and meteorological variables*

Variable	RSV infections	Wind speed	Rainfall	Temp.	Relative humidity	Solar radiation
RSV infections†	1·000	0·271	0·055	0·730**	0·059	0·076
Wind speed (m/s)	0·271	1·000	−0·686**	0·539*	−0·833**	0·760**
Rainfall (mm)	0·076	−0·686**	1·000	−0·152	0·902**	−0·694
Temperature (°C)	0·730**	0·539*	−0·152	1·000	−0·225	0·333
Relative humidity (%)	0·059	−0·833**	0·902**	−0·225	1·000	−0·801**
Solar radiation (W/m^2)	0·076	0·760**	−0·694	0·333	−0·801**	1·000

† Number of monthly respiratory syncytial virus infections.
* Correlation significant at 0·05 level.
** Correlation significant at 0·01 level.

Table 3. *Predictors of the number of monthly respiratory syncytial virus (RSV) infections in multivariate analysis*

Variable	IRR (95% CI)	*P* value
Wind speed (m/s)	22·30 (0·29–1 689·60)	0·160
Rainfall (mm)	1·008 (1·00–1·01)	**0·048**
Temperature (°C)	3·14 (1·56–6·31)	**0·001**
Relative humidity (%)	1·00 (0·70–1·43)	0·980
Solar radiation (W/m^2)	0·99 (0·96–1·02)	0·579

IRR, Incident rate ratio; CI, confidence interval.
Bold font indicates statistically significant values.

positive correlation (Spearman's $\rho = 0{\cdot}902$, $P < 0{\cdot}01$), the only problem being with collinearity. We therefore performed two separate negative binomial regression models: the first included rainfall, but not relative humidity, while the second considered relative humidity but not rainfall. In addition, both models included wind speed, solar radiation, and temperature as predictor variables. While in the first of these two models, temperature (IRR 3·15, 95% CI 1·70–5·86, $P < 0{\cdot}001$) and rainfall (IRR 1·008, 95% CI 1·00–1·01, $P = 0{\cdot}011$) were the only independent predictors of the number of monthly RSV infections, in the latter, temperature (IRR 2·75, 95% CI 1·23–6·17, $P < 0{\cdot}001$) was the only independent predictor of the outcome variable. Likewise, when we performed similar separate analyses for other pairs of highly correlated predictor variables (wind speed–relative humidity and solar radiation–relative humidity), temperature and rainfall were the only independent predictor variables associated with the number of monthly RSV infections. Furthermore, when we constructed an additional negative binomial regression model excluding both relative humidity and wind speed due to their strong positive correlation, temperature was the only independent predictor of the outcome variable (data not shown).

DISCUSSION

The present study shows that in Bogota, a tropical Latin American city situated slightly above the equator, RSV is a highly significant cause of ALRI in infants and young children, and although it remains active throughout the year, it is especially prevalent during the 3-month period from March to May, the first rainy season of the year in the city. Moreover, the findings of the present study suggest that the city's average temperature and rainfall are the meteorological variables most strongly associated with RSV isolation in hospitalized children with ALRI in Bogota.

Our findings provide preliminary but fundamental information that may be useful for more accurately predicting RSV epidemics and for gaining a better understanding of how epidemics of RSV begin and are sustained in Bogota and most likely in other similar tropical LMIC countries. This knowledge may help the planning and implementation of strategies aimed at optimizing the use of both health resources and services, especially in those regions which do not perform local virological surveillance, by anticipating the periods of greatest RSV circulation according to the continuous monitoring of meteorological variables, which is routinely performed in several tropical cities worldwide. These strategies include, although are by no means limited to, deciding when to start and when to discontinue the application of passive prophylaxis against RSV for high-risk infants and deciding when other methods of controlling RSV should be instituted, such as the establishment or strengthening of programmes designed to provide education for staff and family members on hand hygiene and the cohorting of infants with ALRI in hospitals, as a useful way to limit the nosocomial spread of RSV [14].

In our study, although RSV activity was continuous throughout the study period, there was a clear and abrupt increase in the absolute number of RSV ALRI cases during the 3-month period from March to May, the first rainy season of the year in the city. In our analyses we found that temperature and rainfall were the only meteorological variables independently associated with the number of monthly RSV infections. There are two possible explanations for these findings: first, although it is believed that the rainy season is colder than the drier one, during the drier season the temperatures are high during the day but drop below 0 °C at nights and in the early mornings, resulting in lower mean temperatures compared to the rainy season. Second, despite the fact that relative humidity is the meteorological variable most consistently associated with RSV activity in the equatorial zones and in other areas of tropical weather [6], in our study relative humidity was not associated with the number of monthly RSV infections in the multivariate analyses. However, relative humidity showed a strong positive correlation with rainfall in the bivariate analysis (Spearman's $\rho = 0{\cdot}902$, $P < 0{\cdot}01$), and rainfall was an independent predictor of the number of monthly RSV infections in our analyses. Our findings coincide with other studies performed in tropical and subtropical countries which show that the seasonality of RSV is associated with the rainy period of the respective cites [6]. In Singapore, an island country with a non-seasonal tropical rainforest climate, uniform temperature, high humidity, and abundant rainfall, RSV is associated with higher temperatures [15]. In Hong Kong, a city situated just south of the Tropic of Cancer with a humid sub-tropical climate, RSV epidemics have been described as being more frequent during the rainy season, when the temperature is hot [16]. Our findings also agree with previous reports that have shown that in addition to the effect of climatic conditions, latitude is also associated with RSV activity in the community. Welliver *et al.* reported that in regions close to the equator the activity of RSV is associated with higher relative humidity and temperature, and even modest shifts northward or southward from the equator result in an inverse relationship between humidity, temperature, and RSV activity, due to the drier, colder air [17]. Our results also align with previous studies that have shown that in contrast to temperate climates, where outbreaks of RSV are well described and occur during the autumn, winter, and/or spring months, in tropical regions, RSV would appear to be continuous throughout the whole year, the incidence peaks are less prominent, and the association of ARLI with meteorological variables seems to be less clear (pseudo-$R^2 = 0{\cdot}0851$) [18]. Although it is possible that factors other than meteorological ones may be responsible, at least in part, for the associations found in our study (e.g. very high rainfall might drive populations indoors where RSV would spread more readily [19]), there are at least two scientific reasons which might explain a direct association between RSV activity in the community and various meteorological variables. First, certain climatic factors can favour the survival, stability, and spread of infectious pathogens in the environment [20, 21], and second, physiological reactions of the host to certain climatic conditions can affect the susceptibility of the population to presenting ALRI. Yusuf *et al.* have proposed that in tropical and sub-tropical areas, high humidity and stable high temperatures enable RSV to be sustained in large-particle aerosols well enough to allow year-round transmission of the virus [7]. In addition, solar radiation may indirectly affect RSV activity by stimulating vitamin D metabolism in the host, due to the fact that some vitamin D metabolites induce the formation of proteins with direct antiviral activity [22]. Our findings contradict previous findings reported for other cities with similar altitude (>2000 m above sea level), but which are not located in the equatorial zone as is Bogota, such as Mexico City, where it has been shown that relative humidity is the most important predictor of RSV activity [7, 17]. Likewise, RSV activity in Albuquerque, New Mexico, a city with an elevation ranging from 1490 m to >1950 m has been somewhat similar to cities located at altitudes of <1800 m [23]. However, recent evidence has shown that high altitude is linked to high rates of hospitalization and severe disease in children suffering from RSV infections [24, 25]. Taken together, these facts suggest that latitude is a more important factor for RSV activity than is altitude, although altitude may be related to its severity.

The most important limitations of the study are that it was conducted in a referral hospital, in which we determined monthly RSV activity instead of weekly RSV activity, and that we did not take into account the fact that numerous factors other than meteorological conditions can contribute to the spread of RSV in the community. Although RSV isolates in hospitalized children may possibly not reflect the RSV activity in the community and may only represent the extreme of the spectrum of severity of patients with RSV infections, the similarity of the seasonality of RSV with previous surveillance epidemiological reports in the city [26] that included patients with the entire spectrum of disease tends to suggest that our results may be representative of RSV in the community. Although analyses of weekly RSV activity could give a better approximation of the exact moment of viral transmission, meteorological variables have been shown to be a better predictor of monthly than of weekly RSV activity [27]. In addition, although RSV activity in the community can be explained by numerous factors other than meteorological conditions, our main interest was only to analyse the association of this activity with these meteorological factors. However, despite these shortcomings, we believe that our study goes some way towards enhancing our understanding of how epidemics of RSV begin and are sustained in Bogota and probably other similar tropical LMIC.

The main strengths of this study are the fact that a significant number of patients with RSV infection were included, thus reducing random variation and increasing the precision of the estimates. Additionally, patient samples were analysed over more than one time period, allowing comparison of the consistency of trends in seasonality of RSV between the two periods analysed, thus increasing the reliability of the findings.

In conclusion, the present study shows that in Bogota, a tropical Latin American city which is slightly above the equator, RSV is an important cause of ALRI in infants and young children, especially during the 3-month period from March to May, the first rainy season of the year in the city. Furthermore, the study shows that the average temperature and rainfall in the city are the meteorological variables most strongly associated with RSV isolation in hospitalized children with ALRI in Bogota. This research has raised many questions requiring further investigation. It would be interesting to assess the monthly RSV activity and which meteorological parameters are associated with RSV isolates in other tropical countries and over longer periods of time.

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DECLARATION OF INTEREST

None.

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