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Spatial distribution pattern of new leprosy cases under 15 years of age and their contacts in Sobral, Ceará, Brazil

Distribuição espacial de novos casos de hanseníase em menores de 15 anos e de seus contatos em Sobral, Ceará, Brasil

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Abstract *This study's objective was to analyze the spatial distribution pattern of new leprosy cases under 15 years and their contacts. A cross-sectional descriptive study covering sociodemographic characteristics and spatial analysis was carried out. The participants were from the city of Sobral, Ceará and the study was conducted between August 2014 and September 2015. Contacts were identified by the persons responsible for the children. Seropositivity was determined with the NDO-LID antigen, and positive cases were plotted on Voronoi polygons. Nine new cases of leprosy under 15 years of age have been found. The average number of people living with the cases was higher than the number of people living with non-household contacts. All household contacts were aware of other leprosy cases and had a higher rate of seropositive tests than non-household contacts. The index cases lived in the poorest regions of the municipality and hyper-endemic areas. Spatial analysis revealed a cluster of subclinical infection within a radius of 102 meters, suggesting that non-household transmission is related to proximity with seropositive individuals. In conclusion, the search for new leprosy cases cannot be restricted to household contacts.*

Key words *Leprosy, Child, Mycobacterium leprae, Epidemiology*

Resumo *O objetivo deste estudo foi analisar o padrão de distribuição espacial de novos casos de hanseníase em menores de 15 anos e seus contatos. Estudo transversal, descritivo, abrangendo características sociodemográficas e análise espacial. Os participantes eram de Sobral, Ceará e o estudo foi realizado entre agosto de 2014 e setembro de 2015. Os contatos foram identificados pelos responsáveis pelas crianças. A soropositividade foi determinada com o antígeno NDO-LID e os casos positivos foram plotados em polígonos de Voronoi. Nove novos casos de hanseníase em menores de 15 anos foram encontrados. O número médio de pessoas que conviviam com os casos foi superior ao número de pessoas que conviviam com contatos não domiciliares. Todos os contatos domiciliares sabiam de outros casos de hanseníase e apresentaram maior taxa de testes soropositivos do que os contatos não domiciliares. Os casos índice residiam nas regiões mais pobres do município e em áreas hiperendêmicas. A análise espacial revelou um agrupamento de infecção subclínica em um raio de 102 metros, sugerindo que a transmissão não domiciliar está relacionada à proximidade com indivíduos soropositivos. Concluindo, a busca por novos casos de hanseníase não pode se restringir aos contatos domiciliares.*

Palavras-chave *Hanseníase, Criança, Mycobacterium Leprae, Epidemiologia*

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Introduction

Leprosy, one of the oldest diseases that affects men, remains a public health problem in less-developed countries. A trend analysis shows a gradual decrease in new cases of the disease in the world in the last 10 years, from 228,474 in 2010 to 202,185 in 2019[1]. This trend, however, is not uniform in all regions. According to data from the World Health Organization (WHO)[1], 79% of leprosy cases are concentrated in three countries: India, Brazil and Indonesia.

The WHO has periodically been proposing a set of goals and strategies of global reach to be adopted by countries where leprosy is a relevant public health problem[2].

In Brazil, the distribution of leprosy is quite uneven and predominant in the poorest regions: Midwest, North, and Northeast. Between 2009 and 2018, 81.0% of new leprosy cases were in these regions[3]. In 2018, 1,691 new leprosy cases were reported in 153 of the 184 municipalities in Ceará, a state located in Northeastern Brazil which has a high detection rate of 18.6 / 100,000 inhabitants. In the same year, 65 new cases were registered in children under 15 in Ceará, representing 3.8% of new cases[4].

The strategy adopted in Brazil to combat leprosy consists of the detection of new cases and the investigation of all household and social contacts[5]. The goals set by the Ministry of Health for fighting leprosy, until 2022, are: reducing 23% of leprosy cases in children and 12% in adults with degree 2 of physical disability, and to implement channels of notification for discriminatory practices against people affected by leprosy and their families in all units of the federation[6].

Leprosy is transmitted from person to person by nasal secretions; however, the mechanism of transmission of the disease is not yet fully understood. The household contacts of multibacillary patients are at higher risk of acquiring the disease[7,8]. Fine *et al.*[9] found, in a study in Malawi, that only 15% to 30% of new cases had household contacts as a source of infection, suggesting that the majority were infected through contact with non-household cases. Santos et al.[10] in a study carried out in Salvador, Bahia, showed that 17% of children and adolescents under 15 years of age with leprosy reported not having had contact with known cases of the disease. Moura *et al.*[11] showed that living next door to a multibacillary case (MB) may present a similar risk to living in the same house as a patient.

The detection of new cases of leprosy in children and adolescents under the age of 15 years has an important epidemiological significance, as it reveals the recent and continuous transmission of *Mycobacterium leprae* (M. leprae) in the community. Therefore, any investment in the surveillance of contacts in this age group is crucial for the identification and control of the sources of infection[12,1].

Epidemiological studies on leprosy using spatial analysis techniques have been conducted to identify critical areas and risk groups for disease transmission. Previous studies have been done in Brazil in this line of investigation and using spatial techniques to improve the planning of contact surveillance and to control of the spread of M. leprae[13-18].

Considering that children and adolescents, in addition to their home contacts, have other contacts (such as neighbors and schoolmates), sources of transmission of leprosy can be found outside their homes.

This study hypothesizes that spatial analysis can be used to reveal that leprosy transmission occurs both through household and non-household contacts; therefore, the investigation should not be restricted to patients' homes.

Effective strategies for controlling the transmission of leprosy are urgently needed. In this context, this study aims to analyze the spatial distribution pattern of new leprosy cases in children and adolescents under 15 years of age and their household and non-household contacts.

Materials and methods

This is a cross-sectional study with a descriptive analysis of sociodemographic characteristics and spatial analysis of new leprosy cases in children and adolescents under 15 years of age (index cases) and their household and non-household contacts, residing in Sobral, between August 2014 and September 2015.

This study is an excerpt from a larger project entitled "Leprosy in children under 15 years: investigation of potential contacts and use of genetic tools in the study of transmission of *Mycobacterium leprae*" (notice nº 07/2013) of the Research Program for the SUS (PPSUS), held in Sobral, Ceará, from 2014 to 2015.

In 2019, Sobral had an estimated population of 208.953 inhabitants and a Human Development Index of 0.714, measured in 2010 by the Brazilian Institute of Geography and Statistics[19]. The general rate of leprosy detection in the municipality in 2019 was 39.7 new cases / 100,000 inhabitants, with neighborhood detection rates

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ranging from 0 to 169.2 cases / 100,000 inhabitants. This rate characterizes the municipality as having a very high endemicity (20,00 to 39,99 / 100,000 inhab.). The leprosy detection rate in children and adolescent under 15 years of age was 17.9 cases / 100,000 inhabitants in 2019[20], which characterizes the endemicity of the municipality as high (≥10.00 per 100 mil inhab.)[5].

Between August 2014 and September 2015, nine leprosy cases were diagnosed in children and adolescents under 15 years. Four cases were identified in routine consultations, three by active search in homes located in hyper-endemic areas, and two by active search in public schools.

The active search for new cases started in the homes of people with leprosy diagnosed in the year before the study and extended to each case's neighboring homes. Trained community health agents (CHA) did this search, and suspected cases were referred to the primary care centers located closest to the residences. A trained physician made the diagnostic confirmation. The active search among students was carried out in public schools in Sobral[21]. Parents or guardians should mark the location of the dermatological lesions found on the student's body using a tracking card. Children and adolescents under the age of 15 with injuries were referred to the primary care centers. All cases were confirmed by clinical examination, smear test, and skin biopsy.

The index cases, according to the operational classification of the World Health Organization (WHO), were defined as multibacillary (MB) and paucibacillary (PB) and, based on the clinical classification of Madrid, as dimorphic (D), virchowian (V) indeterminate (I), and tuberculoid (T)[22].

Parents or guardians indicated the household and non-household contacts of the index cases. People who lived with the index cases in the five years before their diagnosis were considered household contacts. Anyone who did not live in the same household but had regular contact with the index cases was considered a non-household contact. Regular contact was defined as meetings with a minimum frequency of once every three months in the five years before the index case diagnosis, and who had personal contact with him, such as eating or sleeping together, having an affective relationship, or talking regularly.

Those responsible for index cases (parents or guardians) answered specific semi-structured questionnaires with socioeconomic and demographic information, family composition, social contacts, number of people living with the index cases, and clinical and laboratory data (variables of interest). The economic class of the head of the family was classified using the Brazilian Economic Classification Criteria[23]. All study participants underwent the NDO-LID rapid qualitative serological test[24], for diagnosis of anti-PGL-1 IgM and anti-LID-1 IgG, according to the manufacturer's recommendations (Orange Life®, Rio de Janeiro, Brazil).

The average leprosy detection rates in Sobral neighborhoods and districts, from 2005 to 2016, were estimated by new cases registered in the National Disease Notification System[20] and on linear interpolation data from the 2000 and 2010 censuses of the IBGE[25]. The following endemicity categories were adopted: 1) hyperendemic, detection rate of new cases ≥ 40.00 / 100,000 inhabitants; 2) very high, between 39.99 and 20.00 / 100,000; 3) high, between 19.99 and 10.00 / 100,000; 4) medium, from 9.99 to 2.00 / 100,000; and 5) low <2.0 / 100,000 inhabitants[5].

Spatial Analysis

The index cases' addresses and their household and non-household contacts were georeferenced on MyGeoPosition.com to define the latitude and longitude values, which were inserted in an SPSS database and transferred to QGIS 2.18 to generate maps. Two layers of maps were superimposed, the first with a thematic map with the divisions of Sobral neighborhoods and districts and their respective average rates of detection of new cases per 100 thousand inhabitants, categorized by the leprosy endemic parameters of the Ministry of Health[5]. The second layer consisted of a map with georeferenced data for the residences of the index cases and their household and non-household contacts, identified with the individual history of leprosy illness and the results of the NDO-LID rapid test. The maps' overlapping allowed the visualization of the index cases' location and their household and non-household contacts in the areas according to the endemic level of leprosy. The positivity for anti-M. leprae was analyzed in the Voronoi polygons to estimate the proximity between NDO-LID positive contacts.

Nearest neighbor interpolation (NNI)[26] was used to characterize the disease's spatial patterns and assess cases' clustering in an area. The distance between each point and its closest point was examined using the NNI and compared with the expected values for a random sample of points in a complete spatial randomness (CSR) pattern. The null hypothesis of CSR was tested using the Z statistic. A negative Z score indicates clustering, while a positive score indicates dispersion. The grouping check was performed for NDO-LID-positive contacts and index cases. The bivariate analysis was performed between the variables of interest to the household and non-household contacts. A non-parametric test was performed, specifically, the Mann-Whitney test for comparing the distributions between household and non-household contacts. A significance level of 5% was adopted in all analyzes. The questionnaire data were presented with absolute and relative frequencies and analyzed in SSPS v. 23.0.

Ethical considerations

The study was approved by the Research Ethics Committee of the University in which the study was undertaken, following the Declaration of Helsinki's ethical recommendations. Written consent was obtained from the participants or their guardians. The identity of the cases was not revealed to non-household contacts.

Results

Nine new leprosy cases were studied in children and adolescents under 15 years of age and a total of 151 contacts (36 household and 115 non-household). Index cases had an average of four household, and 12 non-household contacts, with a range of 7 to 25 non-household contacts reported. Each household contact reported regular contact with 6 to 30 people, and each non-household contact reported regular contact with 6 to 23 people. It was not possible to identify school contacts due to refusal from parents or guardians of index cases. One of the participants' fathers did not allow the researchers to access all non-household contacts of the index case.

The index cases' age ranged from 3 to 14 years, and the age range of household and non-household contacts was higher (Table 1). Most of the participants were female, and most families were headed by illiterate parents, mainly among non-household contacts. Most of the participants' families received up to 2 minimum wages and belonged to the lowest economic class. No answers were obtained from two non-household contacts regarding the head of the family's education and income. An average number of 5.9 (1.9) and 4.6 (2.0) people living in the houses of index cases and non-household contacts were observed, respectively ($p < 0.001$). Most houses (137/160; 85.7%) were located on a paved road; they had access to electricity and communication by landline or cell phone. Most houses were made of bricks and had running water, a sewage network, and access to public waste collection (data not shown).

As for the WHO operational classification of index cases, five were PB and four MB. According to the Madrid classification, three cases were tuberculoid (T), two indeterminate (I), two dimorphic (D), and two virchowian (V).

The data in Table 2 indicate no statistical difference between household and non-household contacts concerning current or previous leprosy. The index cases knew someone who has/had leprosy, eight maintained regular contact with these people, and four maintained contact inside and outside the home. All household contacts knew people with leprosy in addition to index cases ($p < 0.001$), and 38.9% (14/36) reported having regular contact with these people. Among the household contacts, regular contact with people with a current or previous leprosy history ranged from 1 to 7. Most of the non-household contacts knew other leprosy cases, and 59.1% (68/115) reported having regular contact with these cases. The rapid NDO-LID test was positive in only three of the nine index cases and was not statistically different for household and non-household contacts ($p = 0.116$).

Figure 1, Map 1A, shows the location of the nine index cases. The distance between the residences of the index cases was an average of 1,701 (390) meters. It is observed that the index cases are located in the peripheral neighborhoods in the urban area of Sobral. The NNI indicated spatial randomness in the distribution of cases (NNI = 1.4; Z-score = 2.3) with an average distance between neighboring cases closer to 643 meters. Map 1B shows index cases and non-household contacts in Sobral and other nearby municipalities (Acaraú, Granja, Massapê, Meruoca, Cariré, and Forquilha). These municipalities are, on average, 53.3 (40.9) km distant from Sobral. On the 1C map, it is possible to see that the houses of all index cases are located in areas classified as hyper-endemic according to the Ministry of Health's parameters.

Figure 2 shows the cases' spatial distribution and negative ($n = 122$) and positive ($N = 25$) household and non-household contacts based on the NDO-LID rapid test, distributed in 35 households in 16 Voronoi polygons. The NNI

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Table 1. Socioeconomic and demographic characteristics of leprosy cases (C) and their household (HC) and non-household (NHC) contacts. Sobral, Brazil, 2014-2015.

All	All	C	HC	NHC	p-value[a]
	N (%)	N (%)	N (%)	N (%)	
	160	9	36	115	
Age in years					
Mean (SD)	28.5 (20.3)	9.2 (3.8)	24.6 (17.2)	31.3 (21.1)	.122[b]
Gender					
Male	73 (45.6)	3 (33.3)	14 (38.9)	56 (48.7)	.497
Female	87 (54.4)	6 (66.7)	22 (61.1)	59 (51.3)	
Education of the head of the family in years (N = 158)					
Illiterate	74 (46.8)	2 (22.2)	13 (36.1)	59 (52.2)	.192
1 to 8	51 (32.3)	5 (55.6)	15 (41.7)	31 (27.4)	
≥9	33 (20.9)	2 (22.2)	8 (22.2)	23 (20.4)	
Family income in MW[c] (N = 158)					
<1	38 (24.1)	2 (22.2)	13 (36.1)	23 (20.4)	.126
1 a 2	94 (59.5)	5 (55.6)	16 (44.4)	73 (64.6)	
3 a 4	26 (16.5)	2 (22.2)	7 (19.4)	17 (15.0)	
Socioeconomic status[c]					
B	17 (10.6)	2 (22.2)	6 (16.7)	9 (7.8)	.167
C	16 (10.0)	1 (11.1)	5 (13.9)	10 (8.7)	
D to E	127 (79.4)	6 (66.7)	25 (69.4)	96 (83.5)	
Number of persons by household					
Mean (SD)	4.9 (2.1)	5.9 (1.9)	5.9 (1.9)	4.6 (2.0)	.001[b]

Abbreviations: C = cases; HC = household contacts, NHC = non-household; MW = minimum wage; SD = standard deviation.
[a] p-Value (Fisher's exact test) comparison among HC and NHC; [b] Mann Whitney Wilcoxon test; [c] MW = US$ 308.87; [d] Brazil's Economic Classification Criteria.

Source: Authors.

Table 2. Clinical and epidemiological characteristics of leprosy cases (C) and their household (HC) and non-household (NHC) contacts. Sobral, Brazil, 2014-2015.

All	All	C	HC	NHC	p-value[a]
	N (%)	N (%)	N (%)	N (%)	
	n = 160	n = 9	n = 36	n = 115	
Current or previous leprosy					
Yes	38 (23.8)	9 (100)	4 (11.1)	25 (21.7)	.225
No	122 (76.2)	0	32 (88.9)	90 (78.3)	
Knowing other cases of leprosy					
Yes	126 (78.7)	9 (100)	36 (100)	81 (70.4)	<.001
No	34 (21.3)	0	0	34 (29.6)	
"Regular contact" with other cases of leprosy[b]					
Yes	90 (56.9)	8 (88.9)	14 (38.9)	68 (59.1)	.033
No	70 (43.1)	1 (11.1)	22 (61.1)	47 (40.9)	
Anti-NDO-LID test (N = 156)					
Positive	28 (17.9)	3 (33.3)	9 (25.7)	16 (14.3)	.116
Negative	128 (82.1)	6 (66.7)	26 (74.3)	96 (85.7)	

Abbreviations: C = cases; HC = household contacts, NHC = non-household contacts;
[a] p-Value: (Mann Whitney's test for comparing HC and NHC); [b] Participants cited more than one regular meeting place with other cases of leprosy.

Source: Authors.

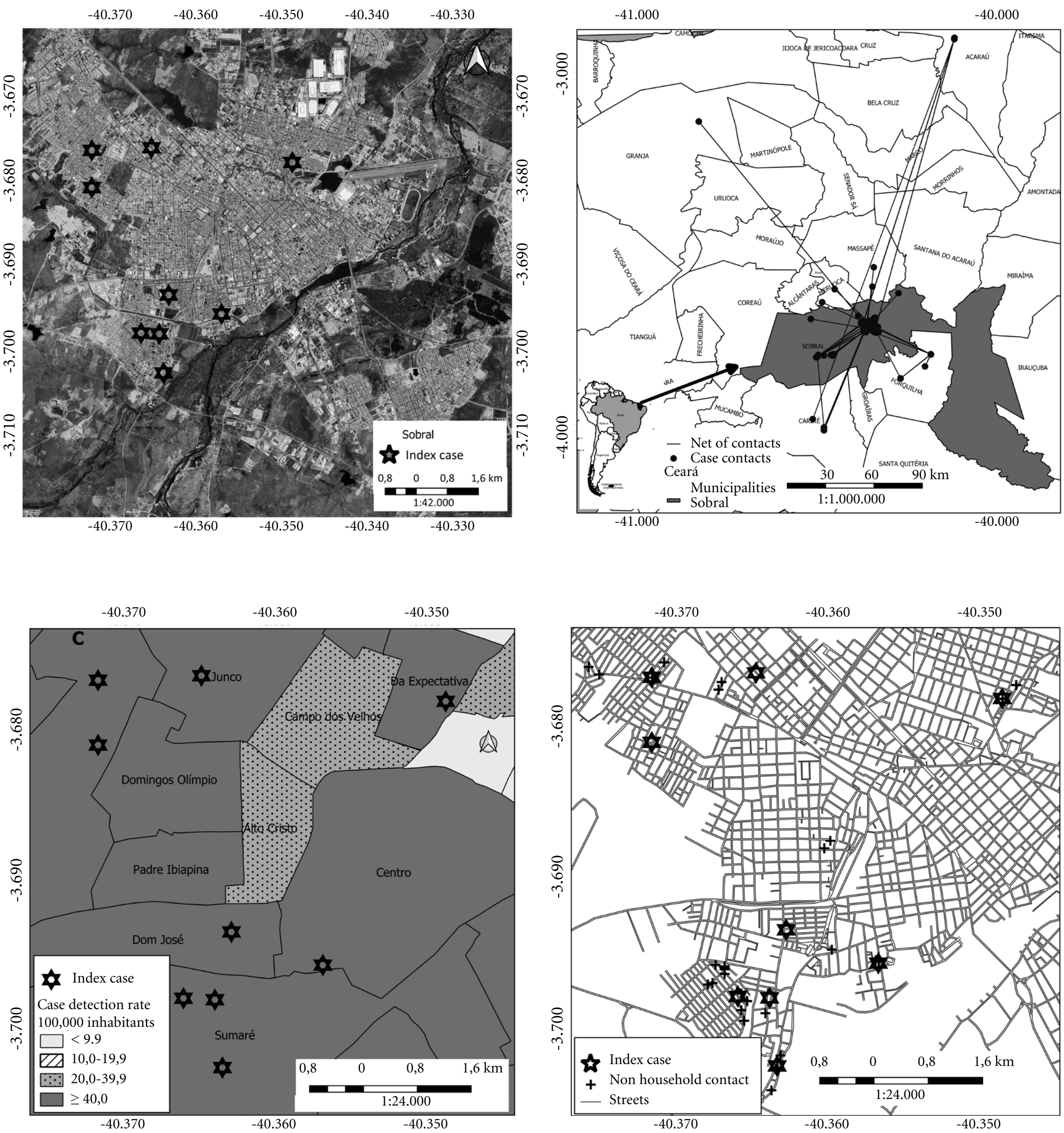

Figure 1. Geographic position of the nine new leprosy cases in children under 15 years, Sobral, Brazil, 2014-2015.

Legend: Map A - detail of the region with the nine cases. Map B - network of cases and their 151 household and non-household contacts, showing that some social contacts are in neighbor municipalities. Map C - new delimited cases in the neighborhoods of Sobral and average rate of detection of new cases from 2005 to 2016, according to the Ministry of Health's classification. Map D - new cases and their non-household contacts.

Source: Authors.

calculated for the positive NDO-LID resulted in a pattern of grouped cases (NNI = 0.3; Z-score = -7.5), with an average distance between the nearest neighbors of 102.3 meters. The groupings of positive NDO-LID participants, however, occurred randomly; that is, the positive NDO-LID individuals were close to both a positive and a negative NDO-LID case.

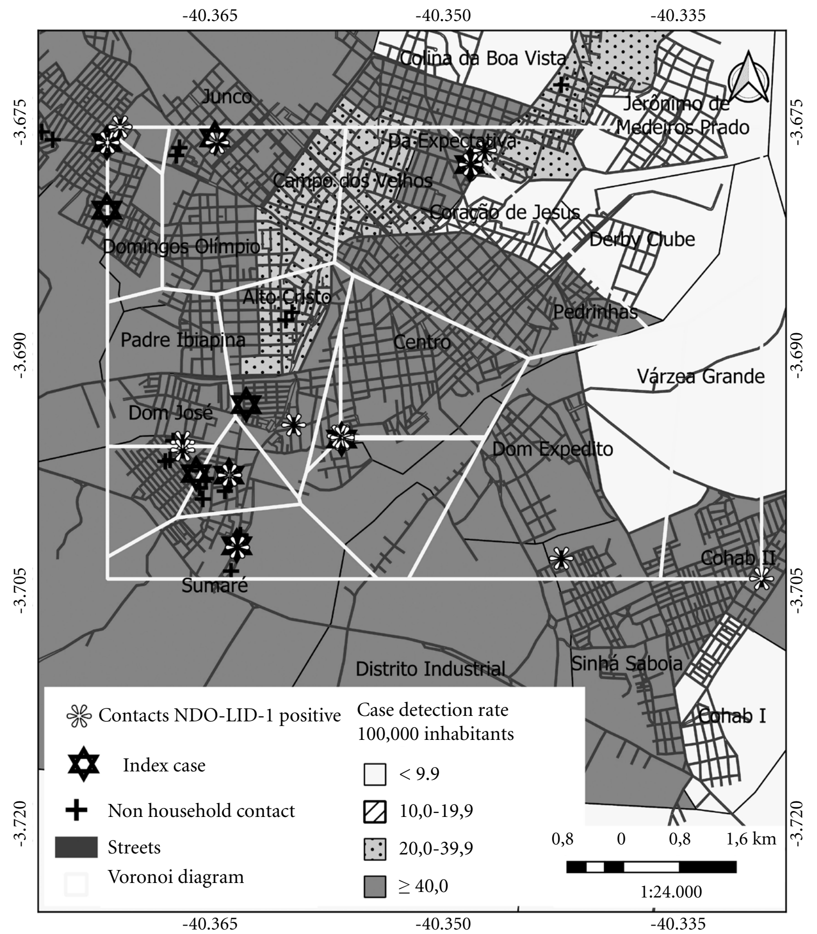

Figure 2. Voronoi diagram created from the concentration of cases and their positive and negative contacts on the NDO-LID rapid test, Sobral, Brazil, 2014-2015.

Source: Authors.

Discussion

The results of the descriptive analysis carried out in the present study show that most index cases and their non-household contacts belong to the lower socioeconomic classes and live in households with a high family density. It was also observed that the presence of disease and subclinical infection, confirmed by the rapid NDO-LID test, did not show any significant difference between household and non-household contacts. The results of the spatial analysis indicated that the index cases reside close to cases with subclinical infection, which present a pattern of clustering among the nearest neighbors of up to 102.3 meters. It is noteworthy that the grouping was random both for cases with a positive NDO-LID test and for those with a negative result.

The neighborhoods where index cases and most of their non-household contacts reside are located in hyper-endemic regions of Sobral, with a high population density and poor socioeconomic conditions[11,27]. It was found that the household group had a significantly higher home density than the non-household group; however, both live, on average, with more people in the same house than the general average of the city, which was 3.7 inhabitants in 2010[28]. Fabri[29] and Gomes et al.[30] showed that a high family density is associated with a high risk of M. leprae infection.

Sobral presents a spatial distribution with well-marked social differences. According to the

2010 census[25], the average number of houses at Sobral headquarters with monthly per capita income of up to 1/4 of a minimum wage was 16.2%. However, some neighborhoods vary between 18% and 25% with this income value. The neighborhoods of the index cases show homogeneity in terms of schooling, income, and social class. The index cases and most non-household contacts are located within the Voronoi polygons, highlighting the association between leprosy and low socioeconomic level, which can be understood as a grouping of contiguous areas, covering the disease and its risk factors. These data may explain the absence of significant differences in the sociodemographic variables between household and non-household contacts. Kerr-Pontes *et al.*[31] already found this association in Sobral city. Several authors have already shown that the low social status of families is an important risk factor for leprosy[32-35]. In this respect, it is important to comment on the study of Nery et al.[36], which showed an association between the reduction of leprosy cases in Brazil and the implementation of the "Bolsa Família" income transfer program, almost two decades ago. These authors draw attention to the current government policies to reduce social and economic safety net programs at a time of economic decline and high unemployment and poverty rates[37]. These political and economic changes generate a high risk of leprosy for a substantial number of Brazilians. After a 13-year decline in leprosy prevalence, the detection of new leprosy cases has already increased by 14% between 2016 and 2018[3].

Household and non-household contacts should not be treated as populations without the disease. It is necessary to reinforce the importance of investigating contacts beyond the cases' homes. The investigation of leprosy cases' contacts is a regular activity of disease control programs, with the primary objective of detecting cases early among those who live or have lived with the newly diagnosed cases and aims to discover new possible sources of infection[5]. As of 2016, according to the Ministry of Health, the investigation of contacts, in addition to households, should include non-household contacts[5]. Despite this change in the recommendation regarding contacts investigation, references about this practice appear only in studies by researchers, and there are no specific publications from the Ministry of Health about the investigation of contacts of leprosy cases. It is possible to infer that this practice is not yet being developed in all Brazilian municipalities. Public health professionals and managers need to be encouraged to use strategies that facilitate access to these non-household contacts.

The fact that household and non-household contacts know and maintain regular contact with other people who have/have already had leprosy indicates other potential sources of infection. One of the leprosy characteristics in endemic areas is the high power of spread[11,38]. This, too, explains the broad pattern of the spatial distribution of leprosy found in this study.

Van Beers *et al.*[8] in a study in Indonesia, reported that of 101 new cases of leprosy over 25 years, 78% could be associated to contact with another leprosy patient (28% of these were identified as household contacts, 36% as neighbors, and the remaining 15% as social contacts). Besides, the authors concluded that 72% of contacts were non-household. These results reinforce the hypothesis that, in hyper-endemic areas, the entire population is exposed to M. leprae. Thus, it is important to expand the scope for investigating contacts of leprosy cases.

The non-household investigation encounters many barriers. The stigma of leprosy is still a problem and addressing non-household contacts is difficult. In this study, some parents or guardians did not recognize schoolmates and teachers of index cases as regular contacts.

The NDO-LID test proved to be a practical method in identifying MB and PB leprosy cases[39]. The LID-1reactivity allows leprosy diagnosis 6 to 8 months before the disease's clinical diagnosis, significantly anticipating treatment, and reducing transmission rates[40].

There was no significant difference between the household and non-household groups concerning the anti-NDO-LID test positivity, which can be explained by the area's high endemicity. Frota *et al.*[41] conducted a case-control study in Sobral using ELISA (anti-PGL-1) and found no significant difference in seropositivity between contacts and non-contacts of leprosy cases. Marçal *et al.*[39] and Fabri *et al.*[42] found similar results in studies carried out in Rio de Janeiro and Uberlândia. Moet *et al.*[43,] in a review article on risk factors for the development of clinical leprosy between contacts, showed that leprosy control could be achieved by identifying the positive contacts for anti-PGL-1 tests.

The study's spatial analysis showed that the index cases were related to non-household contacts, many of them residing in neighboring municipalities (Forquilha, Massapê, Meruoca, Cariré, Granja, Acaraú). From 2014 to 2018,

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these municipalities had average leprosy detection rates that characterized a medium to very high endemicity[2]. This result highlights leprosy expansion in other areas outside Sobral and the idea that the investigation of contacts should not be restricted to geopolitical limits.

Another result of the spatial analysis was that all index cases lived within the urban perimeter and in Sobral neighborhoods, with an average distance between them of approximately 2 km. Although an average distance was found between the index cases, a clustering pattern (Z-score = -7.5) of subclinical infection within a radius of up to 102 meters was observed, suggesting that non-household transmission may be associated with proximity to seropositive individuals. This result suggests that there may be other cases of undiagnosed leprosy in the studied areas. Barreto *et al.*[44], in a study, carried out in the city of Castanhal, Pará, found PGL-1seropositive individuals living within 200 meters of the index case. In Indonesia, Bakker *et al.*[35], in a study conducted in Mar das Flores islands, showed that living at 75 meters or less from a PGL-1 positive person increases subclinical infection risk (OR 1.24).

In Sobral, a study by Arraes *et al.*[33,] using the Voronoi diagrams, demonstrated the presence of *M. leprae* mRNA in open water samples close to the homes of leprosy cases. A case-control study carried out in this city by Kerr-Pontes et al.[32] showed that the habit of bathing in natural streams increases the risk of leprosy. Turankar *et al.*[45], in a study with samples collected from patients and soil from different environments in the endemic region of Purulia district, West Bengal, India, demonstrated the presence of M. leprae mRNA in the peri-household soil of the cases. Bakker *et al.*[35], in a metagenome study conducted in Asia, found that the presence of airborne bacteria was demonstrated at 3 to 5 km from the point of origin, comprising 30% of the phylum Actinobacteria belonging to the genus Mycobacterium. These studies indicate that the disease's prevalence may be related to direct transmission and that the characteristics of the environment may contribute to the high endemicity of some regions.

One of the study's limitations was that there was no comparison between positivity cases for NDO-LID and other specific M. leprae antigens. Another limitation was the restriction of the school population in the study. The stigma hindered the inclusion of more contacts, so some parents or guardians did not feel free to reveal all non-household contacts of the index cases.

Despite the limitations mentioned above, the study showed that transmission sources go beyond geopolitical limits, reaching areas recognized or not as endemic. Spatial analysis techniques can be an important tool to identify groups with a given disease or subclinical infection, and critical areas for leprosy control. Using spatial analysis techniques in their studies, Mencaroni *et al.*[46], Cury *et al.*[47], and Jesus *et al.*[17] identified that the areas and groups at greatest risk for leprosy were associated with low socioeconomic status. The use of spatial analysis techniques made it possible to verify that the geographical distribution of leprosy cases was not exactly that identified in campaigns and in the routine investigation of cases and contacts[47-51]. These findings highlight the importance of directing the actions of identifying cases and investigating contacts with greater precision to prioritize resources and reduce costs. It is worth mentioning that the studies by Queiroz and Scatena[52], Santos *et al.*[53], and Garcia *et al.*[54], whose main objective was to accompany the space-time expansion of leprosy in the process of urban cluster formation, were better understood when employing spatial techniques.

The leprosy control strategy through the investigation of contacts should not be restricted to homes. The assessment of neighbors and non-household contacts is essential to identify sources of disease infection in the community. In Brazil, where primary health care is based on the Family Health Strategy, professionals who work in this care model are essential in conducting an active search for new leprosy cases and tracking contacts. Barreto *et al.*[55], in a study carried out in four municipalities in Ceará, showed that the CHAs, in their home visits, are frequently unable to carry out the entire programmed action agenda. Permanent education strategies in leprosy are essential to increase the active search for suspected cases in the territories and the investigation of household and non-household contacts[56].

Conclusion

The use of spatial analysis techniques with the application of Voronoi polygons proved to be appropriate to identify the distribution pattern of leprosy cases and their household and non-household contacts in Sobral. It was also possible to show the clusters of cases with subclinical leprosy infection, with random distribution of positive and negative NDO-LID cases, all of whom are close neighbors, highlighting the importance of proximity for the transmission of M. leprae.

The spatial distribution pattern of leprosy cases in children and adolescents under 15 years of age and their household and non-household contacts, with active or subclinical leprosy, may indicate M. leprae foci transmission not recognized previously. Given these findings, the search for new leprosy cases cannot be limited to homes or by geopolitical borders. The study reinforced the strong association between low socioeconomic conditions and leprosy.

Collaborations

MSC Linhares: Conceptualization, Methodology, Investigation, Writing; LRFS Kerr: Conceptualization, Project administration, Methodology, Supervision, Resources, Writing - review & editing; C Kendall: Writing - review & editing; RLF Almeida: Validation, Formal analysis, Data curation; A Klovdahl: Methodology; Cristiane C. Frota: Supervision, Writing - review & editing.

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