INTERNATIONAL JOURNAL OF LEPROSY

Volume 53, Number 4
Printed in the U.S.A.

Geographical Variations in the Occurrence of Leprosy: Possible Roles Played by Nutrition and Some Other Environmental Factors[1]

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Leprosy prevalence and incidence rates show considerable geographical variation. Not only from country to country, but also within countries, states and counties, the geographical differences are remarkable. Thus, in Norway during the period 1851 to 1920, the average annual incidence rates of the health districts in the county with the highest endemicity ranged from 8.4 to 92.6 per 100,000 ([11]). In 1936, Guinto and Rodriguez found great variation in the prevalence of leprosy among the villages in Talisay, Philippines ([10]). Similarly, Dominguez, *et al.* recorded a range in prevalence rates from 0 to 63.9 per 1000 in Upper Burma villages ([6]). Also, in India, there is a remarkable variation in the distribution of leprosy (Fig. 1) and the state of Tamil Nadu, at the southeastern coast, has the highest prevalence of 19 per 1000 ([5]).

From the worldwide distribution of the disease, it is evident that leprosy prevails in the poorer areas. Looking at secular trends, several authors have reported a steady decrease in incidence and prevalence as socioeconomic conditions have improved ([11, 15]). Since numerous factors may be involved in the correlation between poor socioeconomic conditions and leprosy, however, these observations per se do not indicate specific etiological factors and are, accordingly, unsuitable for suggesting effective measures for primary prevention.

To illuminate the possible importance of environmental factors responsible for the geographical distribution of the disease, socioeconomic and nutritional conditions were studied in relation to leprosy prevalence rates in 35 villages and field areas in Tamil Nadu, India.

MATERIALS AND METHODS

The project area covers approximately 25 km^2. Being a part of Gudiyatham Taluk of the North Arcot District, it is situated in the northern part of Tamil Nadu. The climate ([14]) is warm throughout the year; mean maximum temperature varies between 30°C and 40°C and the mean minimum between 12°C and 23°C. The average rainfall is 800–900 mm per year.

In 1978, about 55% of the total work force in the project area was engaged in agriculture ([17]). Approximately 70% of the population was living below the poverty line, defined as yearly per capita income of less than 650 rupees ([17]). The proportion of families with all members illiterate was 26% ([17]). The people of this area live either in traditional villages or in so-called field areas, i.e., areas where the habitations lie relatively scattered, often surrounded by cultivated land. Obviously, the population density in field areas is considerably lower than in traditional villages. However, quantification of population density per se was impossible since information on the area in square kilometers was inaccessible. Villages/field areas or aggregates thereof were used as observational units.

Total population and leprosy patients (SLR&TC). Information on population and number of leprosy patients in each of the 35 villages was acquired from the Schieffelin Leprosy Research and Training Centre (SLR&TC) through a detailed house-to-house survey undertaken in February 1982. The total population of the 35 villages was 8597, of which 36.3% were below the age of 15. Altogether, 7428 persons, i.e., 86.4% of the total population, were examined by

[1]Received for publication on 24 October 1984; accepted for publication in revised form on 5 June 1985.

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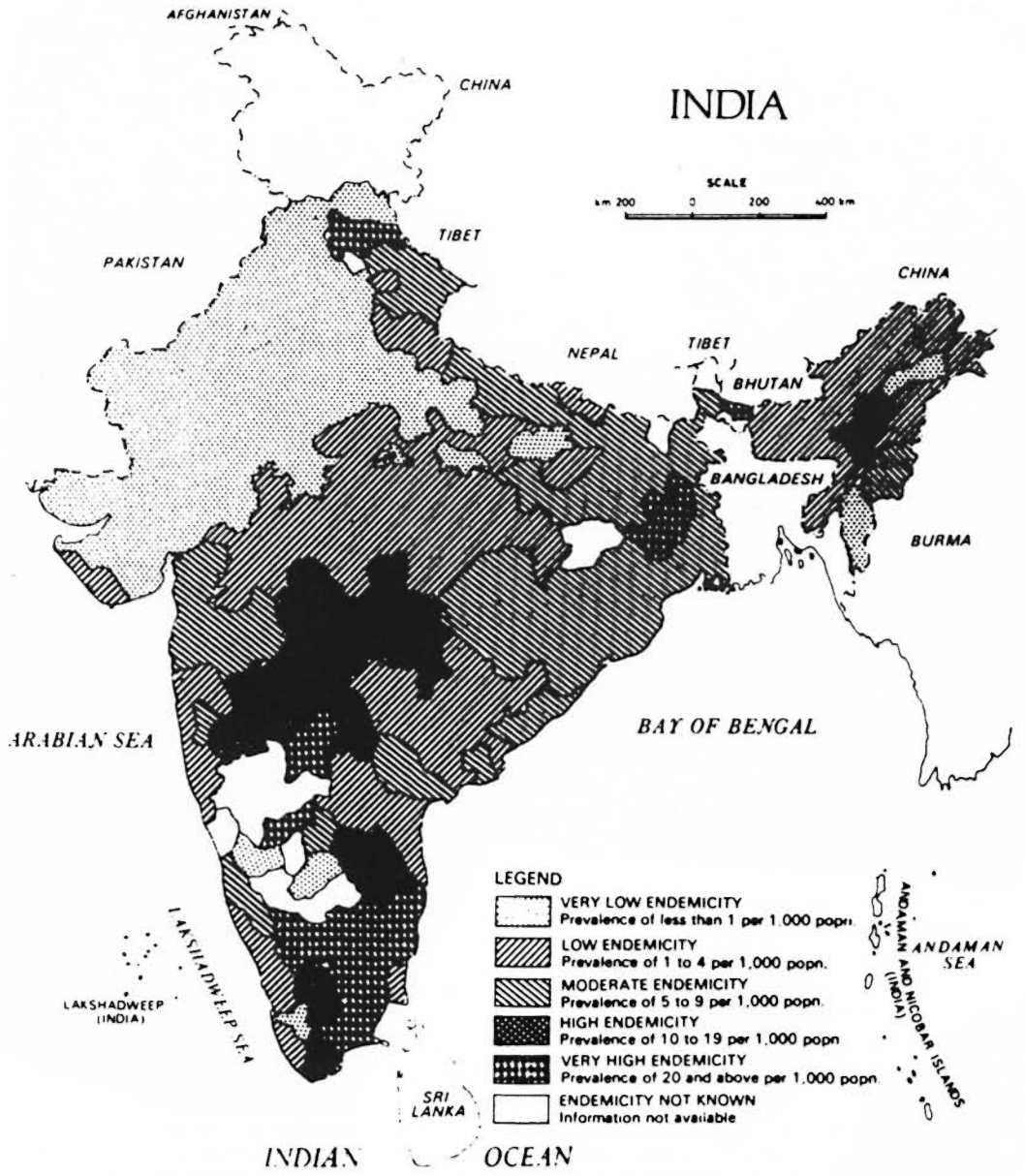

FIG. 1. Leprosy prevalence rates in India. (Source: *Child's Atlas of India*. UNICEF, 1981.)

an experienced field worker, after which any diagnosis of leprosy was verified by a qualified clinical examination and the necessary bacteriological, immunological and histopathological tests. The prevalence rates ranged from 0.0 to 69.9 per 1000 (Fig. 2).

In order to assess the possible role played by the pattern of settlement, the observational units were divided into two groups: 5417 persons lived in 26 traditional villages, while 3180 lived in nine field areas.

Nutritional status of general population. During July to September 1982, in collaboration with the SLR&TC, the nutritional status of the general population in 31 of the 35 villages was assessed by measuring height and weight of the villagers. For practical reasons, data from four villages were unobtainable. To avoid bias in registration, the prevalence rates of the villages were not known to the observer (HS). In each village, every seventh house was selected from a

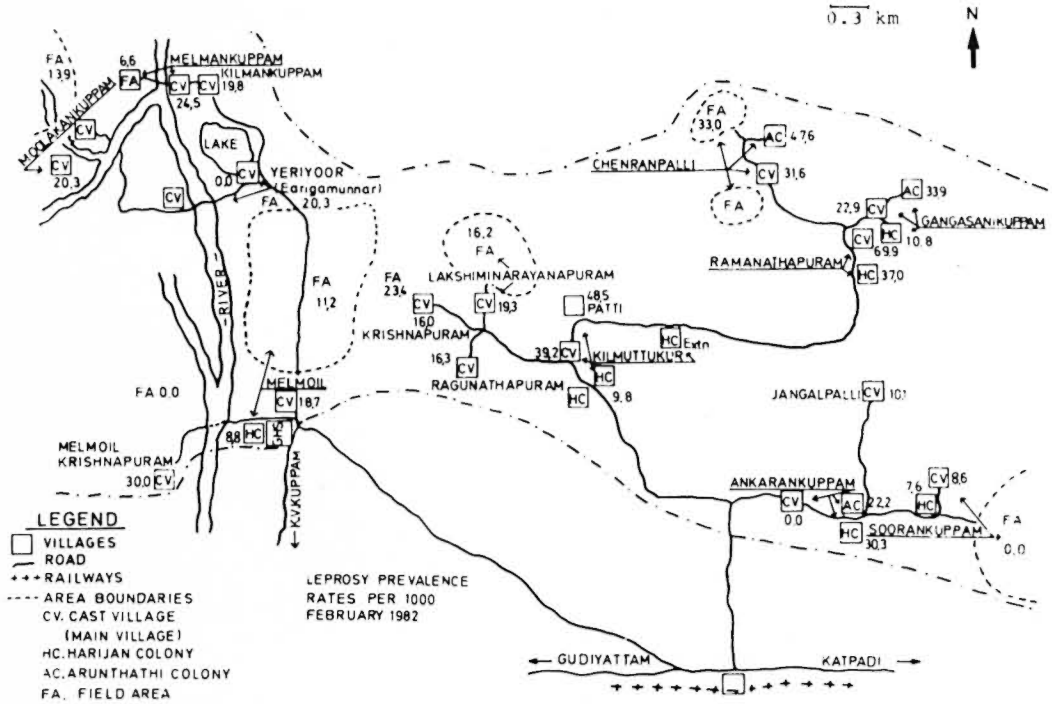

FIG. 2. The 1982 leprosy prevalences per 1000 in 35 South Indian villages and field areas.

prenumbered list and, if necessary, visited twice. A total of 910 persons lived in these houses, and measurements were obtained from 748 (82.2%). This sample amounts to 12.7% of the 5898 persons living in the 31 villages.

Demographic data (RUHSA). The third set of data was provided by the Rural Unit for Health and Social Affairs (RUHSA), an extensive program of community health and development in this region. In 1978, RUHSA undertook a comprehensive socio-economic survey. A series of demographic variables were covered, including family-wise per capita income, highest family education, and nutritional status of children from 1 to 4 years of age (i.e., children until their fifth birthday, excluding infants) measured by the mid-upper-arm circumference (MUAC) ([17]). To the extent possible, cash as well as payment in kind were incorporated into the information on family income. According to Burgess, *et al.* ([1]) and Shakir, *et al.* ([16]), MUAC in children 1 to 4 years of age may be used as in indicator of protein-calorie malnutrition. A MUAC of less than 12.5 cm indicates severe malnutrition, while a MUAC between 12.5 and 13.5 cm indicates moderate malnutrition.

Information on income and education was obtained from all of the families in the study, while the MUAC was measured in 486 out of 853 children 1 to 4 years of age living in these families (57.0%).

Due to inconsistency in the village boundaries used by SLR&TC and RUHSA, respectively, the number of observational units in the analyses of the RUHSA data had to be reduced to 12 aggregates of villages (Fig. 2): 1 = Moolakankuppam caste village (c.v.); 2 = Moolankankuppam field area (f.a.) + Melmankuppam f.a. + Melmankuppam c.v. + Kilmankuppam c.v.; 3 = Yeriyoor c.v. + Yeriyoor f.a. + Melmoil f.a. + Melmoil c.v.; 4 = Melmoil harijan (casteless) colony (h.c.); 5 = Krishnapuram c.v. + Krishnapuram f.a. + Lakshiminarayanapuram c.v. + Lakshiminarayanapuram f.a.; 6 = Kilmuttukur h.c.; 7 = Kilmuttukur c.v. + Kilmuttukur patti; 8 = Chenranpalli c.v. + Chenranpalli arunthathi colony (a.c.); 9 = Ramanathapuram h.c.; 10 = Gangasanikuppam c.v. + Gangasanikuppam a.c. + Gangasanikuppam

TABLE 1. *Population examined for leprosy, leprosy prevalence rates per 1000 (1982), and occurrence of malnutrition in 21 South Indian villages.*[a]

Village	Population examined for leprosy	Leprosy prevalence per 1000	Occurrence of malnutrition[b]
Melmoil Krishnapuram f.a.	35	0.0	37.5
Soorankuppam f.a.	200	0.0	26.3
Ankarankuppam c.v.	206	0.0	11.8
Yeriyoor c.v.	142	0.0	11.5
Melmankuppam f.a.	305	6.6	28.2
Soorankuppam h.c.	132	7.6	50.0
Soorankuppam c.v.	116	8.6	40.0
Melmoil h.c.	228	8.8	23.3
Kilmuttukur h.c.	307	9.8	46.2
Jangalpalli c.v.	198	10.1	29.2
Gangasanikuppam h.c.	93	10.8	55.0
Krishnapuram c.v.	374	16.0	25.0
Lakshiminarayanapuram f.a.	185	16.2	14.3
Ragunathapuram c.v.	246	16.3	28.0
Lakshiminarayanapuram c.v.	207	19.3	37.9
Kilmankuppam c.v.	202	19.8	6.5
Yeriyoor f.a.	148	20.3	25.0
Ankarankuppam a.c.	45	22.2	50.0
Gangasanikuppam c.v.	262	22.9	30.0
Krishnapuram f.a.	214	23.4	5.9
Melmankuppam c.v.	204	24.5	34.5
Melmoil Krishnapuram c.v.	100	30.0	26.7
Ankarankuppam h.c.	99	30.3	44.4
Chenranpalli c.v.	316	31.6	33.3
Chenranpalli f.a.	121	33.1	25.9
Gangasanikuppam a.c.	59	33.9	18.2
Ramanathapuram h.c.	54	37.0	0.0
Kilmuttukur c.v.	153	39.2	31.3
Chenranpalli a.c.	21	47.6	0.0
Kilmuttukur patti	103	48.5	53.3
Ramanathapuram c.v.	143	69.9	28.6
Total	5218	19.0	27.8

[a] c.v. = caste village; f.a. = field area; h.c. = harijan (casteless) colony; a.c. = arunthathi colony.
[b] Expressed by percentage of measured individuals in each village with weight equal to or below the sex- and height-specific 25 percentile for weight.

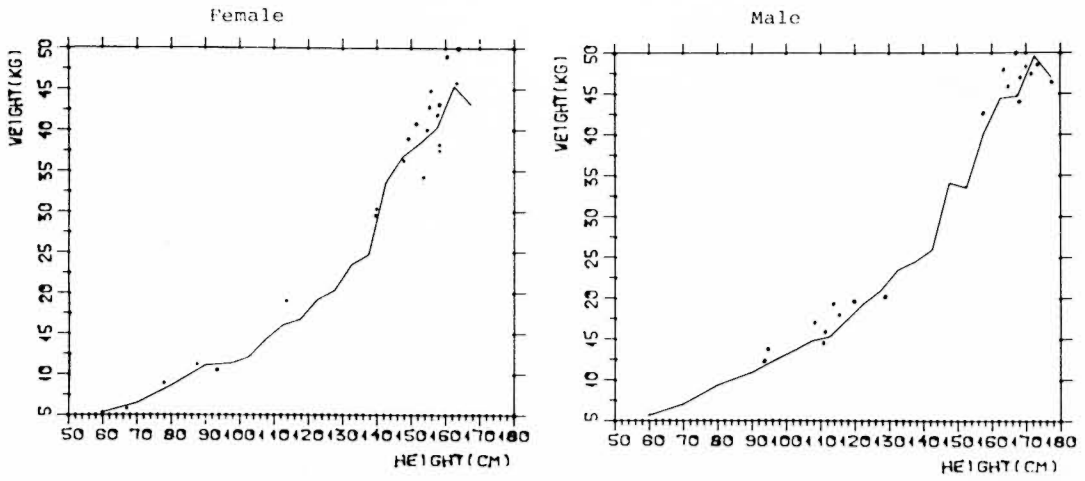

FIG. 3. Sex- and height-specific 25 percentiles for weight in 31 villages in South India. Height-specific weights for the individuals measured in Gangasanikuppam c.v. are indicated by dots.

TABLE 2. *Population examined for leprosy, leprosy prevalence rates per 1000 (SLR&TC, 1982), and demographic data (RUHSA, 1978) for 12 aggregates of villages in South India by increasing prevalence.*

Aggregate	SLR&TC, 1982		RUHSA, 1978					
	Pop. exam. for leprosy	Leprosy prevalence per 1000	Percentage of families with PCI[a] ≤600 Rs[b]	Percentage illiterate families	MUAC[c] in children			
					No. children measured	Coverage (%)	Percentage <12.5 cm	Percentage <13.5 cm
4	228	8.8	83.9	35.7	16	51.6	50.0	56.3
6	307	9.8	87.5	50.0	31	55.0	38.7	67.7
3	1999	13.5	63.8	19.8	162	50.2	20.4	44.4
2	1071	14.9	59.4	26.0	87	50.0	27.6	69.0
5	980	18.4	57.1	26.1	96	82.1	33.3	59.4
1	148	20.3	57.1	33.3	5	50.0	20.0	60.0
10	414	21.7	81.4	31.4	28	50.9	21.4	53.6
12	45	22.2	75.0	50.0	6	66.7	50.0	66.7
11	99	30.3	77.8	44.4	8	57.1	62.5	75.0
8	337	32.6	41.3	24.0	29	87.9	17.2	62.1
9	54	37.0	100.0	60.0	7	87.5	71.4	85.7
7	256	43.0	56.9	9.8	11	45.8	90.9	100.0
Total	5938	17.9	64.2	26.3	486	57.0	29.6	58.0

[a] Per capita income.
[b] Rs = rupees.
[c] Mid-upper-arm circumference in children 1 to 4 years of age.

h.c.; 11 = Angarankuppam h.c.; 12 = Angarankuppam a.c.

Variables

Leprosy prevalence (SLR&TC). From the survey undertaken by SLR&TC in 1982, the leprosy prevalence rates in each observational unit were computed (Tables 1, 2, and 3).

Nutritional status of general population. Accurate information on age is difficult to obtain in many developing countries. Therefore, from the entire sample of 748 persons, sex and height specific percentiles for weight were constructed, percentiles which are independent of age ([18]).

TABLE 3. *Number of inhabitants by pattern of settlement and according to whether or not affected with leprosy.*[a]

Pattern of settlement	No. exam. for leprosy	Not affected	Affected	Prevalence
Village	4799	4702	97	20.2
Field area	2636	2602	34	12.9[b]
Total	7435	7304	131	17.6

[a] Prevalence rates are stated as per 1000 (1982).
[b] Significantly less than leprosy prevalence in villages, p = 0.03, chi-square test with Yates' correction.

To describe the occurrence of malnutrition in each of the 31 villages, the proportion of persons in each village with values equal to or below the 25 percentile was calculated (Table 1). As an example, in Figure 3, height–specific weights for the individuals measured in Gangasanikuppam c.v. are plotted in the percentile graph. Of the 40 persons measured, 12 had values equal to or below the 25 percentile, giving the variable the value of 30.0% (12/40).

Demographic variables (RUHSA). For each of the 12 aggregates the following variables were computed: a) poverty, expressed by the proportion of families having a yearly per capita income of 600 rupees or less (Table 2); b) illiteracy, expressed by the proportion of families with all members illiterate (Table 2); and c) malnutrition in children 1 to 4 years of age, expressed by the proportion of such children with a MUAC of less than 12.5 cm and 13.5 cm, respectively (Table 2).

Statistical analyses

Yates' corrected chi-square test was used to compare the prevalence rate in the traditional villages with those in the field areas. Linear regression was used in analyses of possible associations between nutritional,

TABLE 4. *Simple linear regression of leprosy prevalence rates per 1000 (1982) on nutritional status of children from 1 to 4 years of age described by MUAC.*

Percentage of children with	Standard regression coefficient	r^2	p value
MUAC < 12.5 cm	0.564	0.318	0.028
MUAC < 13.5 cm	0.640	0.410	0.012

economic, and educational conditions on the one hand and leprosy prevalence on the other. To incorporate the relative importance of each observational unit into the regression model, the population examined for leprosy in each unit was used as the weight factor. The statistical tests were based on computer packages (BMDP 1981).

RESULTS

Pattern of settlement. In the field areas, the total prevalence rate was 12.9 against 20.2 in the villages, the difference being statistically significant, p = 0.03 (Table 3).

Nutritional status of the general population. No significant correlation was found between the occurrence of malnutrition in the general population and leprosy prevalence rates, standard regression coefficient = 0.074; $r^2 = 0.0055$; p = 0.35.

Demographic data—RUHSA. a) No significant correlation was found between the occurrence of poverty and leprosy prevalence rates, standard regression coefficient = −0.314; $r^2 = 0.099$; p = 0.16. b) No significant correlation was found between illiteracy and leprosy prevalence rates, standard regression coefficient = −0.157; $r^2 = 0.025$; p = 0.31. c) A significant correlation was found between the occurrence of malnutrition in children 1 to 4 years of age as measured by a MUAC and leprosy prevalence rates (Table 4 and Fig. 4).

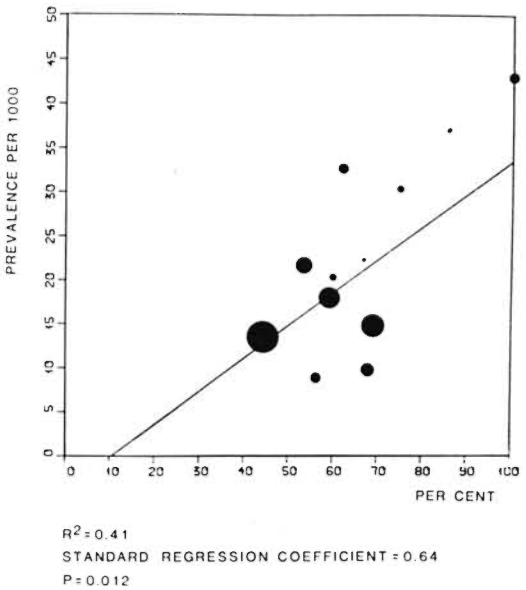

FIG. 4. Regression of proportion in each village-aggregate of children 1 to 4 years of age with a mid-upper-arm circumference (MUAC) of less than 13.5 cm on leprosy prevalence rate as stated per 1000. (To visualize the weighting used in the regression analysis, the area of the dots is proportional to the population examined for leprosy in each aggregate.)

DISCUSSION

Exposure to *Mycobacterium leprae* should be regarded as a necessary but not a sufficient etiological factor for contracting leprosy. Immunological techniques have demonstrated that a large number of persons exposed may become infected without developing any signs or symptoms of leprosy (9). The apparent extreme rarity of secondary cases in nonendemic areas as demonstrated in the Netherlands (13) suggests that contact patterns alone do not determine the distribution of clinical leprosy (7). Moreover, the concept that, in endemic areas, the higher incidence among household contacts, and especially in contacts of lepromatous patients, is due largely to massive transmission of *M. leprae* is questionable. Thus, patterns of risk factors responsible for the susceptibility to leprosy, both of genetic and environmental origin, are assumably more uniform within the household. Possibly both mechanisms are at work, i.e., the transmission of large amounts of the infectious agent within the family and the common pattern of risk factors within this social unit.

In spite of considerable epidemiological interest, exact knowledge about the relationship between environmental factors and leprosy is scarce. The acquisition of relevant data is laborious and, in many areas, impossible. Furthermore, even if data are accessible, inherent problems exist because incidence rates and, even more, prevalence rates, due to the long incubation period and

duration, reflect a situation several years prior to the recording of the etiological factors in question. These reservations should also be taken into account when interpreting the findings of the present study.

The finding that leprosy was less frequent in the open fields may seem inconsistent with the general impression that leprosy is primarily a rural disease. However, it must be emphasized that all parts of the project area should be considered rural. The finding might also be related to population density. However, in a large-scale study undertaken in Gudiyatham Taluk, Rao, *et al.* found no significant correlation between density of population and leprosy prevalence ([14]). Thus, the higher prevalence in the villages might be due to other environmental factors, e.g., bad hygienic conditions, overcrowding and malnutrition.

Neither the occurrence of poverty nor illiteracy was correlated with leprosy prevalence. The fact that trade in this region is largely based on a barter economy makes per capita income an inaccurate measure of socioeconomic status, even though payment in kind was incorporated to the extent possible into the data on family income.

The lack of correlation with illiteracy is, again, apparently in contrast with the findings of Rao, *et al.* ([14]). In their study, there was an inverse relationship between percentage of literates in the general population and leprosy prevalence. However, the educational status of every individual, as recorded by Rao, is obviously more precise than mapping the highest family education level.

The nutritional level of the general population was not correlated with leprosy prevalence. On the other hand, nutritional status of children from 1 to 4 years of age seemed to be of importance for the distribution of the disease. This finding is consistent with current hypotheses regarding leprosy, immunocompetence and malnutrition. Thus, immunity against *M. leprae* is considered to be dependent upon cell-mediated immunity ([8]). As pointed out by Chandra ([4]), malnutrition, even of moderate degree, is almost invariably associated with impaired cell-mediated immunity. Furthermore, Chandra has shown that fetal malnutrition, especially if the child does not show evidence of catch-up growth, is associated with severe, long-lasting deprivation of cellular immunity ([2]). Moreover, infectious diseases common in parts of the world where malnutrition is prevalent may further depress cellular immunity, either indirectly through increased malnutrition, e.g., in diarrhea and febrile illness, or directly by suppressing T-cell functions, e.g., in measles and other viral diseases ([3, 8]).

As pointed out by Jopling, "it is probable that in endemic areas, the majority of [leprosy] infections occurs in childhood, . . . the long incubation period and the unobtrusive early signs can account for many children becoming adults by the time a diagnosis is made" ([12]). Accordingly, in light of present knowledge, the findings of this study suggest malnutrition in childhood, with resulting immunoincompetence, as a potential etiological factor. This interpretation is consistent with the data from Norway during the last century, showing an inverse association at the farm level between production of food and the occurrence of leprosy ([11]).

A prospective orientation might have been desirable for illuminating the relationship between environmental factors and leprosy. Such a study would involve the mapping of every individual in a population at risk with regard to relevant factors such as leprosy contacts, hygienic conditions, socioeconomic and nutritional status. Assuming an incidence rate of 1 per 1000 per year, a child population of 10,000 surveyed during a period of 5 to 10 years would seem sufficient to distinguish patterns of associations. The requirements of personnel and economic resources for a study of this dimension are obviously considerable, and they can hardly be met in countries where leprosy is prevalent today, unless the study is incorporated into already existing health programs. However, in countries with a well-developed health service system, it should be possible to embody a study of this kind in already established routines. Keeping in mind the possible significance of malnutrition in childhood, it would be natural to incorporate such a study into the community health services of pregnant women, infants, preschool and school children.

If the hypothesis of an association be-

tween malnutrition in childhood and susceptibility to leprosy can be confirmed, programs for preventing malnutrition among children may prove instrumental also in the fight against leprosy.

SUMMARY

The considerable variation in leprosy prevalence among 35 villages and field areas in South India was compared with variations in their socioeconomic and nutritional conditions. Using villages/field areas and aggregates thereof as observational units, leprosy prevalence rates were found to be significantly lower in field areas than in villages. Moreover, there was a significant correlation between the occurrence of malnutrition in children 1 to 4 years of age and the prevalence of leprosy. The possible association between the occurrence of malnutrition in childhood and leprosy is discussed in light of the present knowledge of leprosy, immunocompetence, and malnutrition. Strategies for further illumination of the hypothesized importance of malnutrition among children are discussed.

RESUMEN

Se comparó la variación en la prevalencia de la lepra en 35 poblados urbanos y rurales del sur de la India con la variación en sus condiciones socioeconómicas y nutricionales. Se encontró que los índices de prevalencia fueron significativamente menores en las áreas rurales que en las urbanas. Además, hubo una significante correlación entre la ocurrencia de malnutrición en niños de 1 a 4 años de edad y la prevalencia de la lepra. En el trabajo se analizan las asociaciones posibles entre lepra, desnutrición e inmunocompetencia en los niños y se discuten las estratégias más adecuadas para estudiar la hipotética importancia de la desnutrición en la susceptibilidad de los niños a la lepra.

RÉSUMÉ

On a mis en relation les variations considérables observées dans la prévalence de la lèpre et dans 35 villages des régions du sud de l'Inde, avec les différences de conditions socio-économiques et nutritionnelles. En utilisant comme unité d'observation les villages combinés aux régions, et des combinaisons de ces unités, on a démontré que les taux de prévalence de la lèpre étaient significativement plus faibles quand on les rapportait à des régions plutôt qu'à des villages. En outre, la prévalence de la lèpre présentait une corrélation significative avec la présence de malnutrition chez les enfants âgés de 1 à 4 ans. On discute d'une possible association entre l'existence de malnutrition pendant l'enfance et al lèpre, à la lumière de ce que l'on sait à présent de la lèpre, des phénomènes d'immuno-compétence, et de la malnutrition. On envisage également des stratégies qui devraient permettre d'élucider plus avant l'importance éventuelle de la malnutrition chez les enfants.

Acknowledgments. The field work for this study was made possible only through the guidance from and cooperation of the staff at SLR&TC. We are especially indebted to E. P. Fritschi, M.B.B.S., D.Orth., F.R.C.S.; C. J. G. Chacko, M.D., Ph.D.; V. K. Pannikar, M.B.B.S., and Mary Jacob, M.D., for offering necessary facilities and valuable advice.

We would also like to express our gratitude to RUHSA and its staff, especially Daleep S. Mukarjee, M.B.B.S., M.Sc., D.T.P.H., and V. G. Krishnamurthy, M.Sc., M.A., for preparing the demographic data.

Furthermore, we are most grateful for the advice and guidance from M. Steinhoff, M.D., and P. S. S. Rao, M.A., M.P.H., F.S.S., at the Christian Medical College, Vellore.

We would also like to thank cand.real Trond Riise at the EDB Section of the Faculty of Medicine, University of Bergen, for assistance in the statistical analyses performed.

The study was financially supported by the Norwegian Research Council for Science and the Humanities (NAVF) and the Damien Foundation. The support is gratefully acknowledged.

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