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The intensity of transmission of hepatitis A and heterogeneities in socio-environmental risk factors in Rio de Janeiro, Brazil

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Abstract

The objective of this work was to assess the intensity of transmission of hepatitis A in Rio de Janeiro, Brazil. We also used the estimation of the parameters of a deterministic model to study the effects of risk factors. Age-specific seroprevalence of antibodies against hepatitis A virus (HAV) was obtained from a survey screening in a city of the metropolitan area of Rio de Janeiro, in 1997. From the seroprevalence data, we estimated the age-dependent force of infection (λ) and the average age of first infection (A), using a deterministic model. To evaluate the influence of the environmental risk factors, we estimated the same parameters stratifying the sample for the selected socio-environmental risk factors: the number of years of schooling of the female responsible for the house, crowding within the bedroom, number of water taps and fittings, and the presence of sewage in front of the house. For the whole sample, the maximum force of infection estimated was 0·12/year and the average age of infection was 10·1 years. This last parameter decreased as the number of persons per bedroom increased, and also when the number of water taps and the number of years of schooling of the woman responsible for the house decreased. The proposed environmental interventions may lead to a decrease in the intensity of transmission of HAV and an increase in the average age of first infection in the next few years. This may have public health implications, since hepatitis A is more severe in adults. In this context, specific vaccination programmes may be necessary, as in developed countries.

Keywords: hepatitis A, transmission, environmental risk factors, deterministic model, force of infection, Brazil

Introduction

Seroepidemiological studies of hepatitis A have been carried out since the 1970s when commercial kits for laboratory analysis became available. In general, an association has been reported between the seroprevalence of antibodies against hepatitis A virus (HAV) and socio-environmental conditions (SIEBKE *et al.*, 1982; MORALES *et al.*, 1992).

The main route of transmission for hepatitis A infection is faecal–oral and/or direct contact (person–to–person) (KOFF, 1998). Factors that contribute to the transmission of the infection are associated with 2 specific domains, the household environment and the neighbourhood (CAIRNCROSS *et al.*, 1996; MÄUSEZAHL *et al.*, 1996; CDC, 1999; STRUCHINER *et al.*, 1999). The environmental conditions of these domains are strongly related to the socio-economic status of the residents, and the improvement of community sanitation has been shown to reduce the occurrence of infection, especially in the 2 first decades of life (TAPIA-CONYER *et al.*, 1999; TANAKA, 2000).

To quantify the dynamics of hepatitis A transmission, some authors have modelled hepatitis A seroprevalence data from cross-sectional surveys using different stochastic or deterministic models (SCHENZLE *et al.*, 1979; YANG & CHANG, 1990; KEIDING, 1991; AMAKU, 2001). We used a deterministic model to estimate the force of infection (λ) and the average age of acquisition of the first infection (A) with hepatitis A using seroprevalence data from a large survey carried out in the municipality of Duque de Caxias, an area of intervention of a major sanitation programme in Rio de Janeiro State, Brazil (RIO DE JANEIRO, 1993). The average age at first infection can be estimated from the force of infection, and both parameters can be assessed using seroprevalence data (MASSAD *et al.*, 1995).

After obtaining the parameters for the whole sample, we considered a stratification of the sample based on some risk factors that are reckoned to influence the transmission of hepatitis A infection. The stratification of the parameters can supply a first approach to the impact that such interventions could have on the modified and stabilized environment and on the dynamics of transmission of infectious diseases such as hepatitis A.

Methods

Study site

The study was located in the county of Duque de Caxias, in greater Rio de Janeiro, Brazil, an intervention area of the Guanabara Bay Pollution Control Programme. The average household had 4 members and lived in a house with 4·4 rooms which generally included at least one bedroom and one bathroom. Piped water was supplied to 81·6% of households and a further 15·9% used well water only. There was no formal sewage system but 48·1% of households used septic tanks discharging to the rainwater drainage network. Only 43·6% of households benefited from solid waste collection. The average household head had 5·3 years of schooling and a monthly income, which at the time of the study would be equivalent to approximately US$294, or approximately double the Brazilian minimum wage at the time. Among the 43 census tracts within that area, 19 were selected randomly for the study. In 1991, they encompassed a population of 29 729 living in 7565 households (FIBGE, 1991).

Design and conduct of the study

The study began before the completion of sanitation interventions in the area (time zero). The seroprevalence survey for total antibodies against HAV was carried out in 1997. The sample population was se-

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lected at random among the residents of the study area after conducting a census of all households. The sample size was calculated by a random sampling technique considering the seroprevalences obtained in the pilot study in each of the following age groups: 1, 2, 3, 4, 5, 6, 7, 8, 9, 10–14, 15–19, 20–29, and ≥30 years (ALMEIDA *et al.*, 1999).

The fieldwork lasted from June to December 1997. Households of selected individuals were visited to collect blood samples, after obtaining written consent from the subjects or, for children, from their guardians. Interviews were carried out to collect information on the physical and sanitary conditions of the house and environs, and the socio-economic status of the family (ALMEIDA *et al.*, 1998). The age-specific seroprevalence results are summarized in Table 1.

Data analysis

After obtaining the seroprevalence data of the individuals and socio-environmental data for the respective families, a database was constructed for data analysis and mathematical modelling. Using mathematical modelling to analyse the age-dependent force of infection and the corresponding average age of first infection according to the socio-environmental variables showing significant correlation with hepatitis A infection, we estimated the effects of environmental interventions as a first approximation.

Steps of data analysis and mathematical modelling

The age-dependent force of infection, $\lambda(a)$ (where a represents age), which is defined as the per capita rate at which susceptible individuals acquire infection, can be described as a non-negative function, with a null value at birth due to the protection given by maternal antibodies. If we suppose that the force of infection rises to a peak at the age corresponding to the maximum number of infections, with a subsequent decline in higher ages, we can assume, according to the suggestion proposed by FARRINGTON (1990), the following model

$$\lambda(a) = k_1 a e^{-k_2 a} \quad (1)$$

where k_1 and k_2 are parameters to be fitted. In the above function, we supposed an exponential decline, whose intensity is related to the parameter k_2. The parameter k_1, on the other hand, is related to the initial rise of the force of infection, and also to its amplitude.

The proportion of seropositive individuals of age a, $S^+(a)$, can be related to the force of infection through

Table 1. Age-specific seroprevalence of hepatitis A in 3068 individuals in Duque de Caxias, Rio de Janeiro State, Brazil, 1997

Age group (years)	No.	Positive n (%)	95% CI
1	342	21 (6·1)	3·8–9·2
2	368	28 (7·6)	5·1–10·8
3	324	45 (13·9)	10·3–18·1
4	285	80 (28·1)	22·9–3·7
5	240	77 (32·1)	26·2–38·4
6	238	97 (40·8)	34·5–47·3
7	205	90 (43·9)	37·0–50·9
8	185	90 (48·6)	41·3–56·1
9	156	94 (60·3)	52·1–67·9
10–14	245	149 (60·8)	54·4–66·9
15–19	175	138 (78·9)	72·1–84·7
20–29	152	138 (90·8)	85·0–94·9
≥30	153	149 (97·4)	93·44–99·3

95% CI, 95% confidence interval.

the so-called catalytic approach (e.g. GRENFELL & ANDERSON, 1985)

$$\lambda(a) = \frac{dS^+(a)/da}{1 - S^+(a)} \quad (2)$$

Considering $\lambda(a)$ given by equation (1), we can integrate equation (2) to obtain an expression for $S^+(a)$

$$S^+(a) = 1 - \exp\left\{\frac{k_1}{k_2^2}\left[(k_2 a + 1) \times e^{-k_2 a} - 1\right]\right\} \quad (3)$$

We fitted this function to the seroprevalence data by the maximum likelihood method, assuming a binomial likelihood, once each individual is considered to be either seropositive or seronegative. After fitting the parameters k_1 and k_2, we can estimate the age-dependent force of infection. It follows that the average age of acquisition of first infection is (ANDERSON & MAY, 1985):

$$A = \frac{\int_0^L a\lambda(a)[1 - S^+(a)]da}{\int_0^L \lambda(a)[1 - S^+(a)]da} \quad (4)$$

where $[1 - S^+(a)]$ is the proportion of susceptible individuals with age a, and L is the human lifespan for that community, considered here as equal to 60 years. We can also calculate another parameter related to the proportion of HAV antibody-positive individuals: the age in which $\lambda(a)$ has its maximum value, a_{max}.

The average age of first infection depends on the parameters k_1 and k_2 of the fitted $S^+(a)$ function [equation (1)]. Accordingly, we can estimate a confidence interval for the average age of infection based on the variance-covariance matrix of the fitting parameters. We used a Monte Carlo algorithm as described by AMAKU *et al.* (2001).

After this stage of analysis, we estimated the force of infection and the average age of first infection, stratifying the data sample for selected variables representing socio-economic status and sanitary conditions. These variables were: the number of years of schooling of the female responsible for the household, crowding (persons per bedroom), the number of water taps and fittings, and the presence of sewage in front of the house. The selection of these variables was based on another analysis (for risk factors), using the database restricted to children aged 1 to 9 years, including all environmental and domestic variables (ALMEIDA *et al.*, 2001).

They were incorporated into the analysis as follows:

(i) Years of schooling of the woman responsible for the house: 1 = none to 7 years of schooling (incomplete primary education); 2 = eight and more years of schooling (complete primary education or more).
(ii) Crowding (persons per room used for sleeping): 1 = up to two persons; 2 = more than two, up to three persons; 3 = more than three persons.
(iii) Number of water taps and fittings: 1 = two taps or less; 2 = three or more taps.
(iv) Presence of an open sewage channel in front of the house: 1 = present; 2 = absent.

Results

In total 3271 sera samples from individuals, aged from 1 to 83 years, were collected and 3068 (94%) answered the household questionnaire.

Figure 1 shows the proportion of seropositives by age (a), the curve fitted by the maximum likelihood method and the force of infection by age $\lambda(a)$ for the whole sample.

We can see that the proportion of seropositive cases grows faster after 3 years of age. This is the time when a

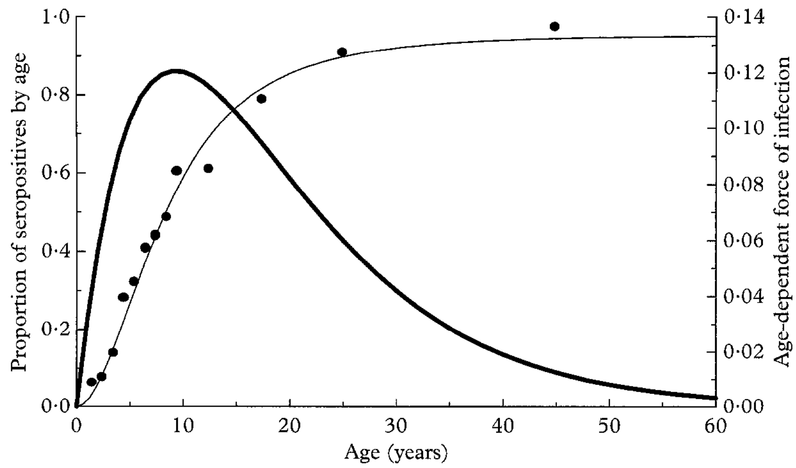

Fig. 1. Seroprevalence data, the corresponding fitted curve (thin line) and the age-dependent force of infection (thick line) of hepatitis A for 3068 individuals in Duque de Caxias, Rio de Janeiro State, Brazil, 1997.

child begins to play with other children (socialization). At around 30 years of age almost all the population is infected. The maximum force of infection estimated for hepatitis A in the whole sample was 0·12/year and average age of first infection was 10·2 (±0·4) years.

Figures 2 and 3 show the age-dependent proportion of seropositives and force of infection stratified by the selected risk factors. The age corresponding to the $\lambda(a)$ maximum (a_{max}) decreased as the number of persons per room increased. The opposite happened with the number of water taps and the number of years of schooling for woman responsible for the house. If there was a sewage channel in front of the house the parameter decreased too. The difference between the curves of force of infection could be observed for all variables, notably 'crowding' and 'number of water taps'.

Table 2 shows the age corresponding to the maximum force of infection (a_{max}), the respective force of infection (λ_{max}) and the average age of first infection, for the whole sample and for the selected variables. The lowest ages corresponding to the $\lambda(a)$ maximum and the lowest average ages of first infection were found

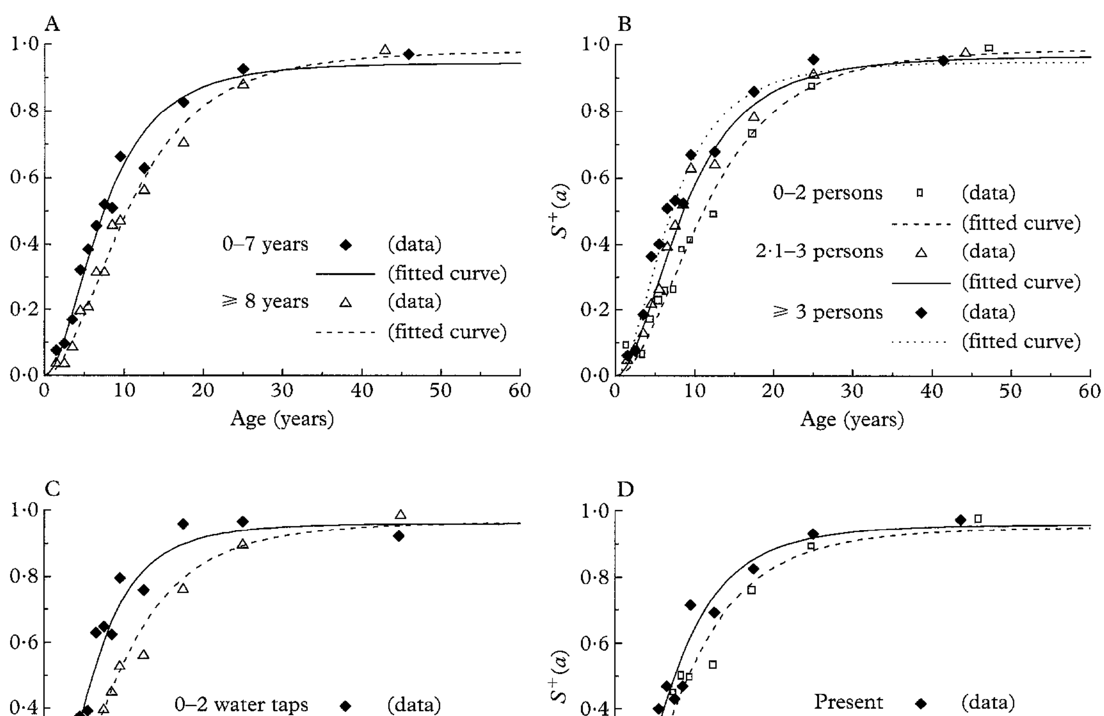

Fig. 2. Seroprevalence of hepatitis A for 3068 individuals in Duque de Caxias, Rio de Janeiro State, Brazil, 1997, by risk factors: (A) years of schooling of female responsible for the house; (B) crowding (persons per bedroom); (C) number of water taps and fittings; and (D) presence of sewage channel in front of the house. $S^+(a)$, proportion of seropositive individuals by age.

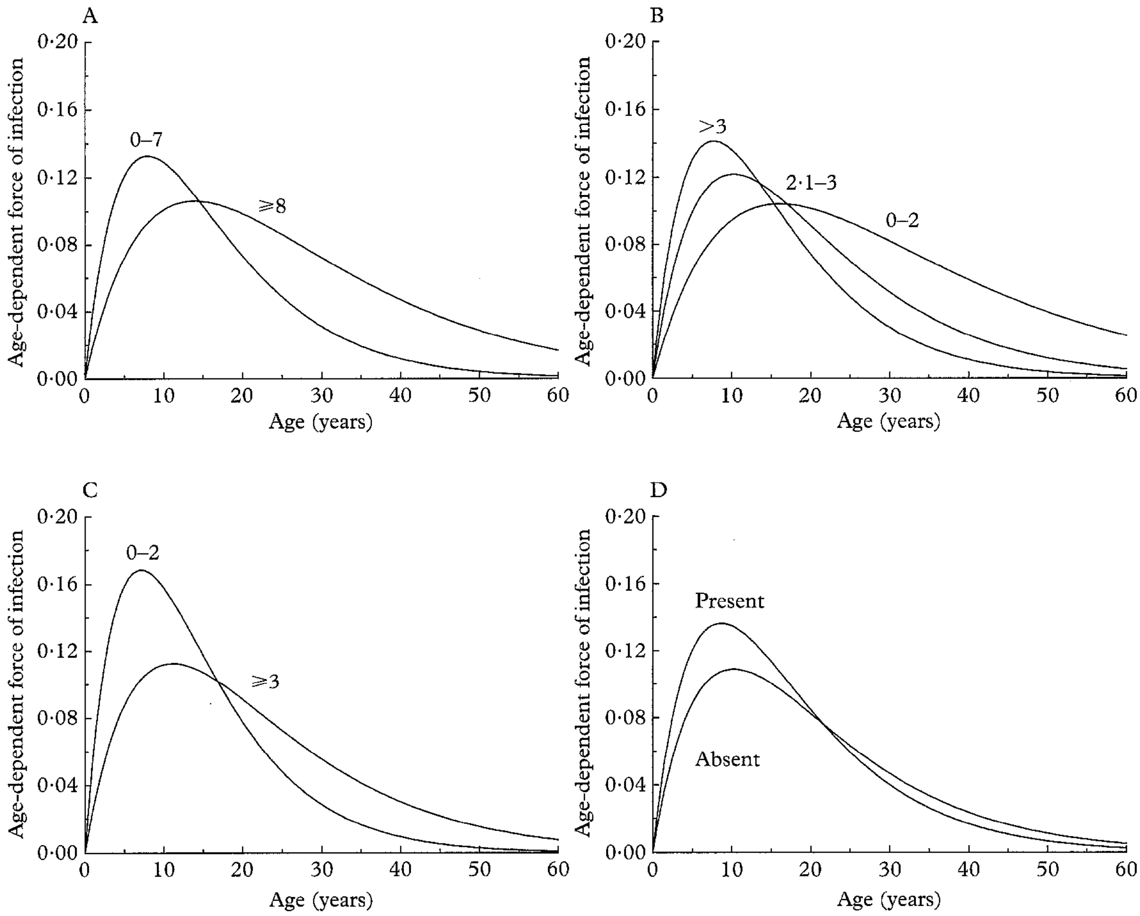

Fig. 3. Age-dependent force of infection of hepatitis A for 3068 individuals by risk factors in Duque de Caxias, Rio de Janeiro State, Brazil, 1997: (A) years of schooling of female responsible for the house; (B) crowding (persons per bedroom); (C) number of water taps and fittings; and (D) presence of sewage channel in front of the house.

Table 2. Age corresponding to the maximum force of infection, respective force of infection and average age of first infection for the whole sample, and selected socio-environmental conditions for hepatitis A in Duque de Caxias, Rio de Janeiro State, Brazil, 1997

Variable	a_{max} (years)	λ_{max} (per year)	Average age of first infection (years ± 1 SD)
Whole sample	9·3	0·12	10·1 ± 0·2
Schooling of female responsible for house (years)			
0–7	7·9	0·13	9·0 ± 0·2
≥8	13·9	0·11	12·5 ± 0·5
Crowding (persons per bedroom)			
>3·0	7·7	0·14	8·7 ± 0·5
2·1–3·0	10·2	0·12	10·4 ± 0·8
0·1–2	16·1	0·10	13·2 ± 0·6
Number of water taps and fittings			
0–2	7·1	0·17	7·5 ± 0·3
≥3	11·1	0·11	11·2 ± 0·3
Open sewage channel in front of house			
Present	8·6	0·14	9·1 ± 0·2
Absent	10·3	0·11	11·1 ± 0·3

a_{max}, maximum force of infection; λ_{max}, respective force of infection.

with a low level of schooling of the female responsible for the house, high crowding, few water taps (or none at all), and the presence of a sewage channel in front of the house.

Discussion

Models can help us to understand how some factors influence the transmission of an infectious disease (GIESECKE, 1994). They can provide an idea about the moment when the transmission is more intense and how some factors can change this scenario, being also a tool for measuring the impact of a given intervention. Here, we only considered age as a factor when we estimated the parameters. Otherwise, the force of infection curves, stratified by selected variables, are a way to show how some socio-environmental risk factors can change them. We have used the estimation of the parameters of a deterministic model to study the effects of risk factors. We considered this procedure as a first approach to assess the possible health impact of specific environmental interventions that are under way in the study area. This allowed us to see the age at which an individual has the highest chance of being infected if he/she is in a specific condition, and how it could be modified by an intervention that changes this condition. This is very important when a disease has more than one route of infection because it could imply a need to review the disease control strategy.

As expected for an area with poor sanitation, the force of infection of hepatitis A was higher among infants. It rose to a peak at the age of 9, corresponding to the maximum contact rate of susceptible with infectious individuals. This may be related to some sanitation improvements in recent years (TAPIA-CONYER *et al.*, 1999).

ZANETTA *et al.* (1996) estimated the force of infection and the average age of first infection from a seroprevalence survey in another city of Brazil and found an average age of first infection smaller than our result, namely 6·7 years, with a force of infection of 0·15/year, higher than ours.

Other authors have estimated the force of infection for hepatitis A using mathematical models. SCHENZLE *et al.* (1979), with different assumptions, estimated the force of infection for 7 European countries, using a catalytic model. They considered the populations homogeneous with respect to susceptibility and exposure to infection. The data fitted reasonably with the model in some cases but not for the others. They considered that the bad fit for some countries could be related to the failure of the seroprevalence rate to rise monotonically with age.

We know that the effects of each specific intervention are not independent of other applied interventions, which can produce a larger combined effect. Environmental interventions can impact on health conditions in more than one way, acting directly and indirectly. For example, in the medium range, the improvement of sanitary conditions impacts positively on the economic conditions of the area, which can amplify the final effect on the health of the residents. On the other hand, the pre-existing socio-economic status of the family can modify the magnitude of the effects of environmental interventions. They determine conditions in the household, which is the main place where other infectious diseases are transmitted, notably those that depend on a certain pattern of personal and domestic hygiene. We can observe that the household conditions can be heterogeneous between houses although relatively homogeneous from the outside.

Higher levels of mother's education seem to contribute to the protection of children from infection in many ways (CALDWELL, 1994). In general, the female responsible for the household determines the standard of personal hygiene and cleanliness. This is explained, to some degree, by the relationship between education level and access to information on hygiene and health.

Our data show that the age corresponding to the maximum force of infection and the average age of first infection decrease as the number of persons per bedroom increases. Crowding generally affects these parameters of all infectious diseases related to water access and hygiene in the household. Crowding has also been identified as a risk factor for hepatitis A in Portugal (BARROS *et al.*, 1999). The association of hepatitis A with crowding suggests that transmission within the domestic environment—as opposed to the public one—accounts for a significant proportion of all cases (CAIRNCROSS *et al.*, 1996).

Infectious diseases transmitted by the faecal–oral route are obviously affected by the degree of access to safe water (quantity and quality). A good measure of water consumption, as a proxy for that variable, is the number of water taps and fittings (WHITE *et al.*, 1972). Water consumption in a household is also an indicator of hygiene. In our study, we found that increasing the number of water taps and fittings is associated with an increase in the average age of first infection and the age corresponding to the maximum force of infection. This finding is consistent with previous studies, which found an association between water supply and the seroprevalence of hepatitis A (TANAKA, 2000). The improvement of safe water access is the most important intervention that is taking place in the study area now.

Data also showed that the presence of an open sewage channel in front of the house could contribute to the transmission of hepatitis A. Sewage channels, partially obstructed by solid waste, overflow when it rains. On these occasions, some streets concentrate large pools of sewage near the individuals' houses. Children play in these streets and return to the houses with sewage contamination on their shoes. This fact, associated with intermittent water supply, can play an important role on the transmission of faecal–oral diseases (CAIRNCROSS *et al.*, 1996).

Hepatitis A is a disease with many transmission routes: person–to–person; person–environment–person; contaminated food or water; sexual contact; use of intravenous drugs and blood derivative transfusion (SHAPIRO *et al.*, 1992; JOHNSON *et al.*, 1995; BALLESTEROS *et al.*, 1996). The virus can persist in the environment for several months. In the human host, the shedding of virus is short-lived: only a few weeks. This is a possible reason for the fact that sanitation can reduce the seroprevalence of hepatitis A dramatically in a community. It interrupts the person–environment–person route of transmission of the disease, reducing the probability of contact between a susceptible individual and the virus and the generation of new index cases. Within the household, access to safe water and sanitary facilities are fundamental to implement new habits of personal and domestic hygiene, and can also reduce person–to–person transmission and the generation of secondary cases. The force of infection then decreases. Consequently, the number of cases in the whole population also decreases and the seroprevalence of antibodies against hepatitis A virus in the community goes down, mainly among children. As a consequence, the pool of susceptibles in the population increases, and so does the average age of acquisition of first infection. The probability of periodic outbreaks (epidemic waves) increases, and also increases the probability of infected adults showing moderate or severe forms of the disease. Sanitation is very important because it reduces the incidence of many other infectious diseases and influences the nutritional status and growth of children. But, if universal coverage of urban services is implemented, then vaccination emerges as an important strategy to control hepatitis A transmission and prevent the severe cases and deaths.

Meanwhile, many women are naturally immune, passing their antibodies against HAV to their babies during pregnancy. Therefore, it is not recommended that vaccination be implemented during the period when maternal antibodies are present. The next step of this research is therefore to estimate the optimal age for hepatitis A vaccination in Brazil.

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References

Almeida, L. M., Costa, M. C. E., Luiz, R. R., Coletty, P. E., Azevedo, R. S., Machado, V. A., Coeli C. M. & Massad, E. (1998). Soroprevalência da hepatite A no município de Duque de Caxias, Rio de Janeiro, Brasil. *Cadernos Saúde Coletiva*, **6**, supplement 1, 39–48.

Almeida, L. M. de, Azevedo, R. S., Guimarães, A. A. M., Coutinho, E. S. F., Struchiner, C. J. & Massad, E. (1999). Detection of antibodies against hepatitis A virus in eluates of blood spotted on filter paper: a pilot study in Rio de Janeiro, Brazil. *Transactions of the Royal Society of Tropical Medicine and Hygiene*, **93**, 401–404.

Almeida, L. M., Werneck, G. L., Cairncross, S., Coeli, C. M., Costa, M. C. E. & Coletty, P. E. (2001). The epidemiology of hepatitis A in Rio de Janeiro: environmental and domestic risk factors. *Epidemiology and Infection*, **127**, 327–333.

Amaku, M. (2001). *Estudo de parâmetros epidemiológicos através de modelamento matemático: aspectos estacionários, espaciais e temporais*. PhD thesis, Universidade de São Paulo, Brazil.

Amaku, M., Azevedo, R. S., Yu, A. L. F., Castro, R. M., Almeida, L. M. & Coutinho, F. A. B. (2001). Estimativas da incerteza na idade média de aquisição de infecção em modelos epidêmicos. *Tendências em Matemática Aplicada e Computacional*, **2**, 23–31.

Anderson, R. M. & May, R. M. (1985). Age-related changes in the rate of disease transmission: implications for the design of vaccination programmes. *Journal of Hygiene*, **94**, 365–436.

Ballesteros, J., Dal-Ré, R., González, A. & Del Romero, J. (1996). Are homosexual males a risk group for hepatitis A infection in intermediate endemicity areas? *Epidemiology and Infection*, **117**, 145–148.

Barros, H., Oliveira, F. & Miranda, H. (1999). A survey of hepatitis A in Portuguese children and adolescents. *Journal of Viral Hepatitis*, **6**, 249–253.

Cairncross, S., Blumenthal, U., Kolsky, P., Moraes, L. & Tayeh, A. (1996). The public and domestic domains in the transmission of disease. *Tropical Medicine and International Health*, **1**, 27–33.

Caldwell, J. C. (1994). How is greater maternal education translated into lower child mortality? *Health Transition Review*, **4**, 111–125.

CDC (Centers for Disease Control and Prevention) (1999). Prevention of hepatitis A through active or passive immunization: recommendations of Advisory Committee on Immunization Practices (ACIP). *Morbidity and Mortality Weekly Report. Recommendations and Reports*, **48**, 1–37.

Farrington, C. P. (1990). Modelling forces of infection for measles, mumps and rubella. *Statistics in Medicine*, **9**, 953–967.

FIBGE (1991). *Censo Brasileiro de 1991*. Fundação Instituto Brasileiro de Geografia e Estatística.

Giesecke, J. (1994). *Modern Infectious Disease Epidemiology*. London: Arnold.

Grenfell, B. T. & Anderson, R. M. (1985). The estimation of age-related rates of infection from case notifications and serological data. *Journal of Hygiene*, **95**, 419–436.

Johnson, Z., Thornton, L., Tobin, A., Lawlor, E., Power, J., Hillary, I. & Temperley, I. (1995). An outbreak of hepatitis A among Irish haemophiliacs. *International Journal of Epidemiology*, **24**, 821–828.

Keiding, N. (1991). Age-specific incidence and prevalence: a statistical perspective. *Journal of the Royal Statistical Society*, **154**, 371–412.

Koff, R. S. (1998). Hepatitis A. *Lancet*, **351**, 1643–1649.

Massad, E., Azevedo, R. S., Yang, H. M., Burattini, M. N. & Coutinho, F. A. B. (1995). Modelling age-dependent transmission rates for childhood infections. *Journal of Biological Systems*, **3**, 803–812.

Mäusezahl, D., Cheng, F., Zhang, S. Q. & Tanner, M. (1996). Hepatitis A in Chinese urban population: the spectrum of social and behavioural risk factors. *International Journal of Epidemiology*, **25**, 1271–1279.

Morales, J. L., Huber, L., Gallego, S., Alvarez, G., Diez-Delgado, J., González, A., Aguillar, L. & Dal-Ré, R. (1992). A seroepidemiologic study of hepatitis A in Spanish children. Relationship of prevalence to age and socio-environmental factors. *Infection*, **20**, 194–196.

Rio de Janeiro (1993). *Programa de Saneamento Básico da Bacia da Baía de Guanabara: Relatório de Referência para Solicitação de empréstimo ao Banco Interamericano de Desenvolvimento, vol. 1.* Rio de Janeiro: State Report.

Schenzle, D., Dietz, K. & Frosner, G. G. (1979). Antibody against hepatitis A in seven European countries - II. Statistical analysis of cross-sectional surveys. *American Journal of Epidemiology*, **110**, 70–76.

Shapiro, C. N., Coleman, P. J., Mcquillan, G. M., Alter, M. J. & Margolis, H. S. (1992). Epidemiology of hepatitis A: seroepidemiology and risk groups in the USA. *Vaccine*, **10**, supplement 1, S59–S62.

Siebke, J. C., Degré, M., Ritland, S. & Enger, S. C. (1982). Prevalence of hepatitis A antibodies in a normal population and some selected groups of patients in Norway - 1982. *American Journal of Epidemiology*, **115**, 185–191.

Struchiner, C. J., Almeida, L. M., Azevedo, R. S. & Massad, E. (1999). Environmental surveillance based on hepatitis A prevalence and incidence rate estimates from a pilot seroprevalence survey in Rio de Janeiro, Brazil. *International Journal of Epidemiology*, **28**, 776–781.

Tanaka, J. (2000). Hepatitis A: shifting epidemiology in Latin America. *Vaccine*, **18**, S57–S60.

Tapia-Conyer, R., Santos, J. I., Cavalcanti, A. M., Urdaneta, E., Rivera, L., Manterola, A., Potin, M., Ruttiman, R. & Kido, J. T. (1999). Hepatitis A in Latin America; a changing epidemiologic pattern. *American Journal of Tropical Medicine and Hygiene*, **61**, 825–829.

White, G. F., Bradley, D. J. & White, A. U. (1972). *Drawers of Water; Domestic Water Use in East Africa*. Chicago: Chicago University Press, p. 140.

Yang, G. L. & Chang, M. N. (1990). A stochastic model for analyzing prevalence surveys of hepatitis A antibody. *Mathematical Biosciences*, **98**, 157–169.

Zanetta, D. M., Azevedo-Neto, R. S., Silveira, A. S. B., Nokes, D. J., Buratini, M. N. & Massad, E. (1996). Seroprevalence of hepatitis A in a community of São Paulo, Brazil. In: *Abstract Book of 7th International Congress of Infectious Diseases, Hong-Kong, 10–13 June 1996*. pp. 118–119.

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