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The household distribution of trachoma in a Tanzanian village: an application of GIS to the study of trachoma

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Summary

The distribution of active trachoma in an endemic village of approximately 1000 people (Kahe Mpya, Tanzania) was mapped spatially and analysed for associated risk factors and evidence of clustering. An association between distance to water source and active disease was demonstrated, although this was reduced after accounting for the lack of independence between cases in the same household. Significant clustering of active trachoma within households was demonstrated, adding support to the hypothesised importance of intra-familial transmission. The spatial distribution of trachoma was analysed using the spatial scan statistic, and evidence of clustering of active trachoma cases detected. Understanding the distribution of the disease has implications for understanding the dynamics of transmission and therefore appropriate control activities. The demonstrated spatial clustering suggests inter-familial as well as intra-familial transmission of infection may be common in this setting. The association between active trachoma and GIS-measured distance to water may be relevant for planning control measures.

Keywords

Trachoma; household distribution; risk factors; spatial clustering; geographic information systems; Tanzania

Introduction

Trachoma is an eye disease caused by repeated infection with the bacterium *Chlamydia trachomatis*. It is the leading cause of infectious blindness worldwide (Thylefors et al. 1995). An estimated 5.9 million people are blind as a result of trachoma. It is prevalent in poor, dry regions of Asia, Africa, the Middle East, South America and Australia (Thylefors et al. 1995).

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Conflicts of interest statement.

The authors have no conflicts of interest concerning the work reported in this paper.

Trachoma is not uniformly distributed in endemic areas (Katz et al. 1988; Bailey et al. 1989; West et al. 1991). Clustering of trachoma has been reported at district, village and neighbourhood levels; (Katz et al. 1988; West et al. 1991) and clustering of disease has also been found at household and bedroom levels in The Gambia (Bailey et al. 1989). In Mexico, however, no evidence of household clustering was found (Taylor et al. 1985). A number of environmental factors are thought to increase the household risk of active trachoma, including low socio-economic status, parental illiteracy, crowded living conditions, inadequate access to water and sanitation, and eye-seeking flies (Duke-Elder 1937; Dunn 1985; Hollows 1985; Prost and Negrel 1989; West et al. 1989; Courtright et al. 1991; Zerihun 1997; Emerson et al. 1999). Determining whether household clustering of trachoma is a consistent phenomenon may help predict likely modes of transmission, which are as yet poorly understood (Emerson et al. 2000); and help to determine the appropriate level at which to target control interventions.

In this study we map the distribution of active trachoma in an endemic area of northern Tanzania. We analyse household and bedroom clustering of active trachoma, and using a geographic information system (GIS)-based approach, examine its spatial distribution and the association between risk of trachoma and distance to water source and latrine.

Methods

Data Collection

As part of a longitudinal study on the impact of mass azithromycin treatment on trachoma in Rombo District, northern Tanzania, a baseline survey was conducted amongst all residents of the sub-village of Kahe Mpya in July 2000. Characteristics of this population and detailed methods of the study have been reported elsewhere (Mabey et al. 2002) (Solomon et al. 2003). Informed consent was obtained from all subjects or their parents, and participation was voluntary. Both eyes of all consenting individuals were examined using 2.5× binocular loupes. Grading of trachoma was undertaken according to the WHO simplified trachoma grading scheme (Thylefors et al. 1987) by a single examiner (P.A.M.), whose reliability had been previously established (unpublished data). For the purposes of the study, a household was defined as the group of individuals sharing a building or group of buildings within a single plot of cultivated land. Numbers or codes were assigned to each household, bedroom, and latrine in the sub-village, and maps drawn of each compound. The room in which each individual slept was recorded.

In June 2002, the location of the centre of each household, and the position of each bedroom, latrine and water source within the sub-village was determined using a GeoExplorer 3 handheld GPS unit (Trimble Navigation Systems, Sunnyvale, CA, USA). Few differences were found between the original household hand-drawn maps and structures as they stood at the time of GPS data collection. Where discrepancies occurred, spatial information was obtained, as far as possible, for the positions recorded on the original hand-drawn maps. GPS data were later differentially corrected using data collected synchronously on a Trimble Pro XR receiver, using Trimble Reference Station software (Trimble Navigation Systems). Differential correction was performed using Pathfinder Office software version 2.7 (Trimble Navigation Systems). The Geographical Information System

(GIS) software package, ArcView 3.1 (Environmental Systems Research Institute, Inc, Redlands, CA) was used to present and analyse the data

Distance to Water Source and Latrine

Straight-line distances of each household to the water source and to the nearest latrine were determined in ArcInfo. These data were entered into STATA, and the distances were explored as risk factors for the presence or absence of trachoma, using logistic regression.

According to Cairncross (1999), a distance each way of 1km (walking at 4km/h, with no queue at the tap) corresponds to a thirty minute round trip water collection. Using this formula, to maintain consistency with other published studies, the distance in meters has been converted to walking time in minutes.

Clustering within Households and Bedrooms

Maps of the household and bedroom distribution of trachoma were developed in ArcView. Clustering of active trachoma at the bedroom or household level was evaluated in STATA by including a random effect in each logistic regression analysis. For example, with household as the cluster, the probability p_{ij} of person j in household i having active trachoma is modelled as a function of their predictor variables x_{ijk} as follows

$$\log\left(\frac{p_{ij}}{1-p_{ij}}\right) = \alpha + \sum_k \beta_k x_{ijk} + \nu_i$$

where each β is a regression coefficient, and ν_i is a normally distributed random effect for household i . The presence of clustering, within household or bedroom, is tested by the null hypothesis that the variance of ν_i is zero. The reliability of the parameter estimates were checked by varying the number of quadrature points in the numerical integration used to fit the model.

Spatial Clustering

The Kulldorf spatial scan statistic was used to explore the spatial distribution of active trachoma cases (Kulldorf and Nagarwalla 1995). For this, we used the StsWin (SaTScan) software (Kulldorf 2002). This programme uses a circular window moved systematically throughout the geographic space to identify significant excesses of cases. The window is centred on each of a number of possible locations throughout the study area (Kulldorf 1997), and for each location, varies in size from zero to a user-defined upper limit. For the current analysis, the upper limit was specified as the geographic size which includes 50% of the study population, allowing both small and large clusters to be detected. For each location and size of the scanning window, a likelihood ratio statistic is calculated, and a P -value is derived by Monte Carlo simulation. This involves generating simulated datasets under the null hypothesis that the prevalence of disease is uniform inside and outside the window. We used a Bernoulli model because the data are binary (presence or absence of disease), with the denominator being the total number of people in each household. The P -value is the proportion of replicates in which the likelihood ratio exceeds the observed value. The

window size and location with the highest likelihood ratio is defined as the “most likely” cluster (i.e. least likely to have occurred by chance). Secondary clusters are defined analogously. We scanned for clusters with high prevalences but not low ones. It should be noted that this process looks for sharply defined circular ‘clusters’ even though, in fact, clustering may not be circular and is likely to fade gradually over distance, without specific boundaries (Draper 1989). Spatial autocorrelation was estimated by a correlogram of the residuals from a second order kriging surface, fitted to the arc-sine square root transformed household prevalences.

Results

Water source and latrines

The sub-village of Kahe Mpya covers an area of approximately 2km² (Figure 1). There are 184 households divided amongst 15 balozis (groups of between 10-20 families living adjacent to each other). There is one water source within the sub-village: a tap that has poor or absent flow in the dry season. Of the 184 households, 169 had access to their own latrine (92%), 149 had access to a latrine that had screening for privacy (80%), and 113 (60%) had evidence of use.

Prevalence of active trachoma

At the time of the survey, 978 people were living in Kahe Mpya and of these 956 (98%) were examined for signs of trachoma. As noted elsewhere (Solomon et al. 2003), the prevalence of active trachoma (in either or both eyes) in Kahe Mpya was 20.3% (95%CI: 17.8%, 23.0%). As expected prevalence was highest in young children (42% in 1-9 year olds), with a rapid decrease in adolescents and young adults. Amongst older females (above 50 years), active trachoma was a surprisingly frequent finding; 17% of females aged over 50 years had active trachoma compared to only 4% aged 30-49 years. (95%CI: 3.4%, 22.1%, $P=0.002$). In contrast, the prevalence in adult males was low (2% in 30-49 years and 4% in those over 50 years).

Distance to Latrine

No association was found between distance from the household to the nearest latrine and prevalence of trachoma within a household. This may be a reflection of the high proportion of households having a latrine.

Distance to water

The location of the water source in Kahe Mpya is shown in Figure 1. A relationship between the prevalence of trachoma and the GIS-determined time taken to walk to the water source was observed. The prevalence of trachoma was lower in households less than 5 minutes walk away than in more distant households. Amongst households more than 5 minutes away, there was little variation in risk of active trachoma (Figure 2). Using <5mins as a reference, the odds ratios for active disease were 4.5 (95% CI 1.04 – 19.04, $P=0.02$) for 5-15min, 3.21 (95% CI: 0.7-13.9, $P=0.09$) for 15-30min and 4.93 (95% CI 1.12-21.65, $P=0.01$) for over 30min.

Household and Bedroom occupancy

The number of people per household ranged from 1 to 14. There were no cases of active trachoma in single-occupancy households, but there was not a significant relationship between the number of people per household and the prevalence of active trachoma. The number of people sleeping per room ranged from 1 to 9. In a univariate logistic regression analysis, where less than 5 people slept in a room the prevalence of active disease was 18% compared to 28% for 5 or more ($P=0.002$). However, with adjustment for age, the association was not statistically significant.

Clustering Within Households

As illustrated in Figure 1, the disease was not uniformly distributed throughout the sub-village. Eighty-four (46%) of the households in Kahe-Mpya had no cases of active trachoma. Forty-four households (23%) included in the survey had one member who had active trachoma, and fifty-seven households (31%) had two cases or more.

The demonstrated association between trachoma prevalence and age distribution and distance to water suggests that any clustering of cases within households and bedrooms could be due to variation in the household distribution of these factors. Therefore, household was included as a random effect in a logistic regression analysis of the association between trachoma prevalence and age, number per household and distance to water. Significant clustering by household was demonstrated after adjusting for all of these factors ($P<0.001$).

Clustering Within Bedrooms

Similarly, trachoma was not uniformly distributed amongst sleeping rooms (Figure 3). Of a total of 368 bedrooms in the sub-village, 237 (64%) contained no cases. Thus the 196 cases of trachoma were distributed amongst 129 bedrooms. Eighty-three of the bedrooms (24%) had only one case and the remaining 112 cases were found in 46 bedrooms (14%). The results of the random effects model test suggest significant clustering of active cases within bedrooms. Clustering at this level was significant after accounting for age, room size and distance to water ($P<0.001$). However, when this analysis was restricted to those households with at least one person with trachoma, then the clustering was no longer statistically significant.

Distance to water adjusted for clustering

Fitting the random effects model to the logistic regression showed that once the lack of independence between cases was adjusted for, the significance of the association between time taken to walk to the water source and active trachoma was affected. The increase in prevalence at 5-15min and 15-30 min compared to less than 5 minutes was no longer significant. However people living more than thirty minutes from water still had an increased risk of active trachoma after adjustment for clustering, though the level of statistical significance of the association was reduced ($P=0.048$).

Spatial Clustering

Three significant clusters of high rates of active trachoma were identified by SaTScan (Figure 1). The “most likely” cluster ($P=0.005$) identified had a radius of 283 meters, contained 24 households. For this cluster, 21 cases were expected and 40 were observed. Two significant “secondary” clusters were also identified ($P=0.016$ and $P=0.042$). The correlogram showed an autocorrelation of 0.32 for households within 100 meters of each other, but little association beyond that.

Discussion

The age distribution of active trachoma seen in Kahe Mpya is typical of that reported elsewhere (Taylor et al. 1985; Tielsch et al. 1988; West et al. 1991); prevalence was highest amongst young children and declined with age. In contrast to other studies (Tielsch et al. 1988) (Katz et al. 1996) (Schemann et al. 2002), sleeping in crowded conditions was not associated with an increased risk of having active trachoma, once adjusted for age. The effect of adjusting for age suggests that rooms holding more people may be rooms where more young children sleep. Since children are the main reservoir of ocular *C. trachomatis* in this community (Solomon et al. 2003), age appears to act as a confounder in the analysis of bedroom crowding as a risk factor.

Significant clustering of active trachoma within households was demonstrated in Kahe Mpya. This remained significant even after accounting for risk factors that potentially influence trachoma distribution. These findings agree with the results of studies (Bailey et al. 1989) in The Gambia. Household clustering is likely to reflect the passing of infection between family members. It may also reflect common exposure to socio-economic and environmental factors within a household. In common with several previous studies (Ballard et al. 1981; Courtright et al. 1991; West et al. 1991) we also found evidence of clustering within bedroom. However, the failure of this effect to persist when the analysis is restricted to positive households suggests that transmission routes other than those occurring in a shared sleeping place may be important in this setting.

Ideally, disease control strategies should be tailored to the local epidemiology of the disease. The finding in this setting (and others) of household- clustering suggests control programs involving delivery of antibiotics may be more cost-effective if they are targeted at households in which active trachoma is found. A randomised trial conducted in Nepal to evaluate this hypothesis suggested that mass treatment of all children was at least as effective and no more expensive than treatment only of children with active disease plus members of their households (Frick et al. 2001; Holm et al. 2001), but such comparisons should be made in other trachoma endemic areas, too.

The spatial distribution of active trachoma was also explored in this study. Evidence was found for clustering of disease in three areas of the sub-village. A possible explanation for this spatial pattern is that specific environmental risk factors are operating within these areas. However no particular risk factors could be identified in the current study. An alternative explanation is that transmission of trachoma *between* family units in the local area is common. No evidence of spatial clustering was found in The Gambia (Bailey et al.

1989), which may suggest that transmission *between* households is rare there compared to transmission *within* households. These different results may reflect differences in the social organisation and living arrangements in the two settings. Inter-household transmission in Kahe is highly plausible, because neighbouring households within balozis are often from the same extended family, and therefore share strong social connections and close interactions. Indeed, significant clustering of trachoma within the balozi has been found elsewhere in Tanzania (West et al. 1991).

As well as allowing for the display and analysis of the distribution of trachoma, the use of GPS/GIS technology in this study enabled the accurate measurement of straight-line distances from households to latrines and water source. A number of authors have reported that families with latrines have less trachoma than those without (Courtright et al. 1991; Zerihun 1997). Latrines are posited to be protective in trachoma by reducing the volume of faeces lying on open ground, which would tend to reduce the availability of breeding medium for the bazaar fly, *Musca sorbens*, thought to be an important vector of the disease (Emerson et al. 1999). In Kahe Mpya the majority of families have latrines. This study explored the association between the distance of the latrine from the household and trachoma prevalence, with the hypothesis that latrine utilisation would decrease with increasing distance from household to latrine. However no association was found, suggesting that there is insufficient impact of distance on latrine use in Kahe Mpya to affect trachoma transmission, or that the effect is modulated by other factors that were not included in our analyses.

There is one water source in Kahe Mpya. It provides water for the sub-village and areas beyond. A common limitation of studies investigating the association between trachoma prevalence and distance to water is a failure to account for the lack of independence between cases (Emerson et al. 2000). Indeed, in this study, when adjustment was made for household clustering, the strength of the association was reduced. However, there remained a significantly elevated risk of active disease amongst those living more than a 30 minute round trip away, compared to those less than 5 minutes' walk away. This finding seems to correspond to the 'water use plateau' hypothesis of Cairncross and Feachem (Cairncross and Feachem 1993) which suggests that within a thirty-minute round trip of the nearest water source, households do not significantly vary in their overall water consumption. Only households less than five minutes or greater than thirty minutes from the source appear to show an elevated or reduced usage, respectively (Cairncross 1999). Neither water use nor time taken to collect water were explored in the current study, and our interpretation is based on assumptions about likely travel times for distances measured by GIS. Additionally, we have not explored other potential confounders, such as the socioeconomic status of families living close to and remote from the water source. Further exploration in this setting of the relationship between trachoma, water access and water use might be informative.

The importance of various routes of transmission of trachoma in different settings remain unknown. It is hard to disentangle the relative importance of intra- and inter- familial transmission. The presence of significant clustering at household level, and of significant spatial clustering within the sub-village suggest that both may play a role. From a control point of view, the finding of a relationship between distance to water and risk of trachoma

appears promising. A number of studies have indicated an inverse association between facial cleanliness and trachoma (Taylor et al. 1989; West et al. 1989) and this has been linked to distance to water (West et al. 1989); this may be the mechanism underlying the relationship we have observed in this study. Access to water in Rombo - as in other trachoma endemic areas of Tanzania - is poor for the majority of residents. Both here and elsewhere, further studies investigating the merits of improving water supply, and of promoting hygiene (teaching, for example, the relatively low volume of water that can suffice for hand and face washing) may provide further evidence to support the use of these approaches in control programmes.

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Figure 1.

Spatial clustering of active trachoma in Kahe Mpya – the number of cases out of total number of people per household with the location of significant clusters of active trachoma as identified by the spatial scan statistic.

Figure 2.
Prevalence of active trachoma by GIS-determined walking time to the sub-village water source.

Figure 3.

The distribution of cases of active trachoma by bedroom in Kahe Mpya - the location of bedrooms within households with active trachoma