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Mapping sites of high TB transmission risk: Integrating the shared air and social behaviour of TB cases and adolescents in a South African township

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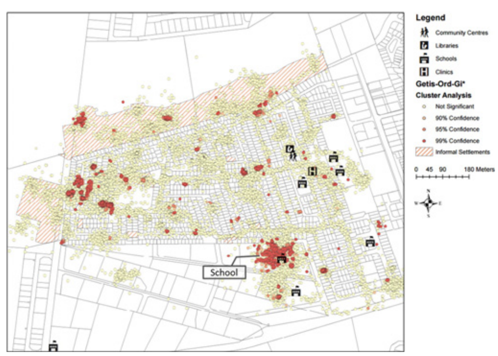
HIGHLIGHTS

- A novel technique to locate congregate sites of TB transmission is presented.
- CO_2/GIS monitors were given to TB cases and adolescents from a high burden community.
- The social behaviour of the adolescent group increased their risk of exposure.
- The community school was found to be a potential TB transmission hot spot.

GRAPHICAL ABSTRACT



Getis-Ord-Gi* cluster analysis highlighting the school as a TB transmission hot spot.

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ABSTRACT

Background: Tuberculosis remains a major public health problem in poverty-stricken areas of the world. Communal gathering places account for the majority of TB transmission in high burden settings.
Objective: To investigate the social behaviour patterns of individuals who have developed TB disease and adolescents at risk of infection. To develop a cheap and effective method to locate transmission hot spots in high burden communities.
Design: Portable, combined CO_2/GIS monitors and location diaries were given to individuals from a South African township. The three groups: newly diagnosed TB patients, recently treated TB patients and adolescents recorded their activities over a median of two days. Rebreathed air volumes (RAVs) at all GIS locations were calculated from CO_2 levels using the Rudnick-Milton variant of the Wells-Riley TB transmission model. Hot spot analysis was performed to determine the communal buildings which correspond to spatially clustered high RAVs.
Results: Analysis of diaries found that the adolescent group spent greater time in congregate settings compared with the other two groups driven by time spent in school/work (new TB: 1%, recent TB: 8%, and adolescents: 23%). Adolescents also changed their location more frequently (9.0, 6.0, 14.3 changes per day; $p < 0.001$). The RAVs reflected this divergence between the groups (44, 40, 127 l; $p < 0.001$). Communal buildings associated with high RAVs were found to be a clinic, two schools and a library. Hot spot analysis revealed the most intense clustering of high RAVs at a community school.

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Conclusion: Our study demonstrates a new methodology to uncover TB transmission hot spots using a technique that avoids the need to pre-select locations. Investigation of a South African township highlighted the high risk potential of schools and high risk social behaviour of adolescents. Consequently the targeting of transmission reduction strategies to schools may prove highly efficacious in high burden settings.

1. Introduction

Global TB prevalence is declining at a rate of 1.5% per annum (WHO, 2014). Nevertheless there are still an estimated 9.6 million new TB case notifications each year (WHO, 2014). In South Africa the rates of TB infection are similar to those of 100 years ago driven by a force of infection estimated to be 4–8% (Wood et al., 2011). This is a rate greater than the pre-chemotherapy era in the industrialised world (Hermans et al., 2015). The WHO strategy of active case finding is resource intensive and has not been shown to have a significant effect on TB epidemiology (Kranzer et al., 2013). In order to have such an impact interventions aimed at reducing the effective contact rate are required (Yates et al., 2016).

Airborne spread of TB demands sufficient physical proximity to share a breathing zone between an infectious case and a susceptible individual. Necessarily this locates transmission events in indoor poorly ventilated buildings frequented by infectious individuals. For adults molecular epidemiology studies (Verver et al., 2004; Glynn et al., 2015; Brooks-Pollock et al., 2011; Buu et al., 2010) together with modelling of social interaction and environmental data (Andrews et al., 2014) point to congregate settings as the most frequent location of such events in highly burdened regions. Household transmission remains significant in childhood (Middelkoop et al., 2009) but becomes less important with age and the positive association between TB infection and residential exposure to adult TB cases is lost by adolescence (>15 years) (Middelkoop et al., 2014).

The estimation of building ventilation can be achieved by the use of CO_2 monitoring provided the presence of a CO_2 source (Menzies et al., 1995). Conveniently humans are highly reliable CO_2 sources with tight regulation of concentration (4%) and an approximate adult production rate of 6 l/min. Linkage to site specific information for room occupancy allows calculation of the rebreathed air fraction for any individual within that room (Wood et al., 2014). From this fraction the Rudnick-Milton variant (Rudnick and Milton, 2003) on the Wells-Riley model gives an approximately linear relationship between rebreathed air fraction and probability of a new TB infection in a susceptible individual assuming the presence of one or more infectors. The efficacy of this approach has been demonstrated in public health field work. In an open-plan office in London incident TB infections following a three month exposure to an infectious staff member were predicted with reasonable accuracy by measuring daily CO_2 levels and assuming an infectious quanta production rate of 13 particles/h (Pankhurst et al., 2012).

For any given community the high risk sites may vary considerably. A low cost, effective technique to identify communal buildings for targeted transmission reduction interventions would be highly desirable. Our study investigated a community with frequent transmission events as demonstrated by an undiagnosed prevalence rate >2000 per 100,000 (Wood et al., 2007) and a latent TB infection rate that reaches 88.0% by age 31–35 (Wood et al., 2010). We sought to characterise the social behaviour of members of this community: both those who had progressed to TB disease and those who are at risk of doing so. In addition we used personal monitoring devices to map CO_2 levels combined with diary reported room occupant numbers to derive average rebreathed air volumes (RAVs). By linking these data to GIS locations we constructed a geospatial map which could be used to identify sites of TB transmission risk.

2. Methods

2.1. Study population

All participants were resident in Masiphumelele a small, peri-urban township 40 km south of Cape Town with an estimated population of 18,000 and a TB notification rate of 2000 per 100,000 (Middelkoop et al., 2015). The study took place during the winter months (May–October) with data collected from 2012 to 2015. Pulmonary TB patients ($n = 12$) were recruited at the time of diagnosis from a clinic in Masiphumelele township. Another group of recently treated pulmonary TB patients ($n = 24$) were recruited from the same clinic shortly after finishing treatment. The median time between completion of treatment and enrolment in the study was 45.5 days (IQR 31–65). The final group were healthy adolescents from the community ($n = 58$) recruited from the Desmond Tutu Youth Centre in Masiphumelele. Enrolment in the study included both the diary section and the CO_2/GIS monitor section.

2.2. Data collection

Each participant completed a questionnaire recording demographic and household details. A continuous diary recording locations visited and number of people present was kept. This was maintained for several consecutive days per participant (median time period of 2 days).

No diary information was recorded for sleep by five members of the adolescent group who recorded time overnight as spent in their own household consequently they were excluded from analysis of sleep but data on their mobility was retained.

2.3. GIS/CO_2 monitoring

For the GIS/CO_2 monitoring, participants were requested to carry a small personal device (previously described (Wood et al., 2014)) at all time throughout the study. The monitor logged values every minute for both GPS coordinates and CO_2 in parts per million (PPM). These data were later uploaded from the device for analysis.

A minimum threshold of 1100 data points in 24 h was set representing location monitoring for >75% of each day (maximum possible 1440 min/day). Not all the monitors logged sufficient data to be included in the analysis and so data from these devices were discarded (Fig. 1). Failure to log data was attributed to either loss of signal, firmware failure or device battery failure with a resultant loss of approximately one third of participants.

To preserve battery life the GIS monitor was fitted with a motion detector such that when stationary for >20 min it turned off. Once movement restarted the monitor turned back on and data recording quickly resumed. This typically occurred during sleeping hours but not during the rest of the day. In order to maintain proportionate location data for mapping purposes and RAV analysis the missing data points were extrapolated from the last known GPS coordinates.

On preliminary testing the GIS monitor was found to have a dither such that successive coordinates for the location of a stationary device varied by a distance of between 0.08 and 10.4 m with a mean of 2.1 m.