Journal of Infection (2017) 75, 191—197

www.elsevierhealth.com/journals/jinf

Tuberculosis transmission in public locations in Tanzania: A novel approach to studying airborne disease transmission☆

Jerry Hella [a,b,c], Carl Morrow [d], Francis Mhimbira [a,b,c], Samuel Ginsberg [e], Nakul Chitnis [b,c], Sebastien Gagneux [b,c], Beatrice Mutayoba [f], Robin Wood [d], Lukas Fenner [a,b,c,g,*]

[a] *Ifakara Health Institute, Dar es Salaam, Tanzania*
[b] *Swiss Tropical and Public Health Institute, Basel, Switzerland*
[c] *University of Basel, Basel, Switzerland*
[d] *Desmond Tutu HIV Centre, University of Cape Town, Cape Town, South Africa*
[e] *Department of Electrical Engineering, Faculty of Engineering and the Built Environment, University of Cape Town, Cape Town, South Africa*
[f] *National Tuberculosis and Leprosy Program, Dar es Salaam, Tanzania*
[g] *Institute of Social and Preventive Medicine, University of Bern, Bern, Switzerland*

Accepted 21 June 2017
Available online 1 July 2017

KEYWORDS
Tuberculosis;
Transmission;
Airborne transmission;
Tanzania;
Transmission hotspots;
CO_2;
Wells-Riley equation

Summary *Objectives:* For tuberculosis (TB) transmission to occur, an uninfected individual must inhale the previously infected breath. Our objective was to identify potential TB transmission hotspots in metropolitan city of Dar es Salaam, Tanzania and to model the annual risk of TB transmission in different locations of public importance.
Methods: We collected indoor carbon dioxide (CO_2) data from markets, prisons, night clubs, public transportation, religious and social halls, and from schools. Study volunteers recorded social contacts at each of the locations. We then estimated the annual risks of TB transmission using a modified Wells-Riley equation for different locations.
Results: The annual risks of TB transmission were highest among prison inmates (41.6%) and drivers (20.3%) in public transport. Lower transmission risks were found in central markets (4.8% for traders, but 0.5% for their customers), passengers on public transport (2.4%), public schools (4.0%), nightclubs (1.7%), religious (0.13%), and social halls (0.12%).

Abbreviations: CI, Confidence interval; CO_2, Carbon dioxide gas; HCF, Health care facility; Mtb, *Mycobacterium tuberculosis*; ppm, parts per million; SD, standard deviation; TB, tuberculosis; WHO, World Health Organization.

☆ **Meeting at which part of the data were presented**: 47th Union World Conference on Lung Health, Liverpool, UK, 26—29 October 2016.

* Corresponding author. Swiss Tropical and Public Health Institute, Socinstrasse 42, 4002, Basel, Switzerland. Fax: +41 31 631 3520.
E-mail address: lukas.fenner@ispm.unibe.ch (L. Fenner).

http://dx.doi.org/10.1016/j.jinf.2017.06.009

Conclusion: For the first time in a country representative of sub-Saharan Africa, we modelled the risk of TB transmission in important public locations by using a novel approach of studying airborne transmission. This approach can guide identification of TB transmission hotspots and targeted interventions to reach WHO's ambitious End TB targets.

Background

One quarter of the world's population is estimated to be infected with *Mycobacterium tuberculosis* (Mtb).[1] Transmission of Mtb occurs when uninfected persons inhale infectious droplet nuclei from the infected.[2] Droplet nuclei with diameters of 1–5 μm can remain suspended in air for many minutes to hours,[3] thus making Mtb highly transmissible in overcrowded locations with poor ventilation. For this and other reasons, tuberculosis (TB) remains a major public health problem worldwide.

One way to estimate the risk of TB transmission begins with measuring environmental levels of carbon dioxide (CO_2) levels.[4,5] CO_2 levels combined with social contact data allow calculation of the volumes of rebreathed air in order to estimate the potential for airborne disease transmission.[6] A modified Wells and Riley equation can be used to estimate TB transmission, taking into account the rebreathed air fraction (estimated from indoor and outdoor CO_2 levels), time at risk, the infectious dose (quanta of contagion), and the number of people occupying the confined space.[4,6,7]

Until recently, only studies from Cape Town, South Africa have used this approach. Additional studies in settings more representative of sub-Saharan African countries, which have the highest burden of TB, are needed. We therefore studied potential TB transmission hotspots in metropolitan Dar es Salaam, Tanzania using this novel, CO_2-based approach to model the risk of TB transmission as the basis for planning intervention studies.

Methods

Study locations and design

We used exposure assessment methods in Dar es Salaam where 22% of 62,952 new TB cases in Tanzania were notified in 2013, making the city a TB hotspot.[8] Adult volunteers carried CO_2 monitors to locations of public importance, and they also recorded the time spent and the number of people at each location. Volunteers collected data between February 2015 and August 2015. We did not include health care facilities (HCF), as waiting rooms are usually open-air in Tanzania and as a study from South Africa indicated that the contribution of HCFs to the annual risk of TB transmission was small with indoor contact accounting only 0.5% of all contacts.[9] We obtained written permission from the Ministry of Health and Social Welfare through the National Tuberculosis and Leprosy Program to collect the infrastructure-related CO_2 data at public locations. In addition, the Ministry of Home Affairs (Tanzania Prisons) issued permission to enter prisons for data collection.

Market

The largest market in Dar es Salaam, known as Kariakoo, has an underground floor, which is populated daily by 100–180 people during each hour of the day. Most retail traders elsewhere in Dar es Salaam make wholesale purchases of agricultural products from this market.

Prisons

The two largest facilities in the Dar es Salaam region with over 1000 inmates were included. One prison is a short-term facility for the temporarily remanded who awaits court rulings, while the other is a long-term correctional facility. While inmates are outdoors during the day, at night they share cells that are occupied by approximately 40 inmates. Prison guards placed the monitors in different cells during the night to collect CO_2 data in the facilities.

Night clubs

We collected data from eight of the largest popular nightclubs in the city that prohibit indoor cigarette smoking. The night clubs were sound proof and relied upon alternative ventilation mechanisms such as closed air conditioning systems.

Public transportation

Public transportation in Dar es Salaam largely relies upon two commuter bus designs with carrying capacities of 15–22 and 32 to 40 passengers.

Religious and social halls

Religious halls consist of mosques and churches with open ventilation complemented by fans for cooling. Social halls, in contrast, have closed ventilation systems that rely on air conditioning, and they are used for family events such as wedding receptions.

Schools

We collected data from colleges and schools (day and boarding schools) in Dar es Salaam. The schools typically have open windows and no other type of ventilation. The classrooms hold 40 to 50 students in each room.

Data collection, definitions and statistical analysis

We collected social contact data using standardized data collection forms (number of people and time at each location) and environmental CO_2 data from the monitors used in previous studies.[4,5,7] The workflow for data collection is presented in Supplementary Fig. 1. Volumes of rebreathed air were calculated based on indoor and outdoor CO_2 levels at specific times, and accounted for the number of people present and assumed a respiration rate of eight