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REVIEW

Mobile phones and malaria: Modeling human and parasite travel

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Summary Human mobility plays an important role in the dissemination of malaria parasites between regions of variable transmission intensity. Asymptomatic individuals can unknowingly carry parasites to regions where mosquito vectors are available, for example, undermining control programs and contributing to transmission when they travel. Understanding how parasites are imported between regions in this way is therefore an important goal for elimination planning and the control of transmission, and would enable control programs to target the principal sources of malaria. Measuring human mobility has traditionally been difficult to do on a population scale, but the widespread adoption of mobile phones in low-income settings presents a unique opportunity to directly measure human movements that are relevant to the spread of malaria. Here, we discuss the opportunities for measuring human mobility using data from mobile phones, as well as some of the issues associated with combining mobility estimates with malaria infection risk maps to meaningfully estimate routes of parasite importation.

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Introduction

One of the biggest challenges facing the African countries considering malaria elimination is the ongoing threat of imported infections between different regions within a country and across borders. In highly endemic regions almost everyone in the population has parasites and most have no symptoms. Asymptomatic individuals are therefore reservoirs of infection that can carry parasites when they travel and contribute to transmission in endemic regions, or renew transmission in areas that remain vulnerable to malaria following control. As transportation infrastructure across Africa improves, the role of importation of parasites carried by asymptomatic people becomes increasingly important, particularly in countries with spatially heterogeneous transmission settings. Tools for understanding human mobility are currently limited, but the near ubiquity of mobile phones in many malaria-endemic countries offers a new way to examine national population dynamics on an unprecedented scale.

Although many qualitative surveys have explored the impacts of travel and transportation on health, economics, and development in Africa,[1] there is a huge deficit of quantitative data on individual mobility from these regions. The definitive data on the topic remain the observational analyses on population movements across the continent by Prothero between 1960 and 1995.[2,3] Since then, most studies have focused on migration and long distance human movements,[4] with very few analyses of regular, short-distance journeys between different regions. Clearly, there is great need for a "theoretical conception of mobility"[5] grounded in quantitative data, not only in order to understand infectious disease transmission, but also for a better understanding of population dynamics in general.

Mobile phones, which have been rapidly adopted across the globe, offer a unique way to track millions of individuals over time and to understand the dynamics of malaria-endemic populations. The use of mobile phones as "human sensors" to measure human mobility patterns is a rapidly growing field.[6,7] Recent work of this kind analyzing call data records (CDRs) from Europe and North America has focused on the development of statistical rules of movement that seem to apply across different spatial and temporal scales.[7–9] Much less is known about patterns of human movement in low-income countries, especially in Africa, although mobility has rapidly increased across the continent in recent years.[10] The types of journey made in low-income countries are different in their range and frequency and occur for different reasons than in the developed world. Migrant workers, seasonal pastoralists, rural-to-urban migrants, and refugees all play important roles in the transmission of infectious diseases ranging from malaria to cholera and HIV.[2,3,5,11]

Understanding how human movements contribute to the spread of disease requires the integration of mobility data with information about infection risk. The human movements that are relevant to the transmission of vector-borne infections like malaria will be different from those that are important for sexually transmitted infections like HIV, pathogens spread through the environment like cholera, or respiratory pathogens such as influenza. For example, most densely populated urban centers experience a high volume of human traffic, making cities critical for the spread of directly transmitted infections. The paucity of mosquito vectors in most cities makes these movements less important for malaria transmission, however. Mathematical models can be used to understand how human mobility impacts the spread of infection.[12–18] For example, studies of the spread of influenza have simulated mobility using census or airline data and applied gravity models to scale them to global travel patterns, using a dynamical model of the spread of infection within subpopulations.[9–14]

Here, we focus on the application of mobile phone data to understanding human mobility in relation to malaria, although much of the discussion could apply to many infectious diseases. Others have reviewed the importance of understanding human mobility for reducing malaria transmission and containing drug resistance,[19–22] and the data sources currently available.[23,24] We discuss the opportunities that mobile phone data provide and the challenges associated with using call data records (CDRs) for understanding how malaria parasites are carried between regions. We first briefly describe the range of movements that can be measured using mobile phone data, and their relevance for transmission. We then discuss the spatio-temporal resolution of CDRs, issues related to sample bias and validation, and review studies that have used CDRs to estimate human mobility. Finally we focus on applying these estimates to malaria data in a meaningful way, and the key gaps in biological knowledge that limit the accuracy of our estimates.

The impact of mobility on malaria

The range and frequency of human movement patterns, coupled with the mode and dynamics of disease transmission, will determine the impact of human mobility on infectious disease epidemiology. Stoddard et al.[19] adapted Prothero's landmark studies to identify the importance of these spatiotemporal scales for vector-borne diseases (Fig. 1), and Le Menach et al.[20] describe the importance of human and mosquito movements for malaria epidemiology. Local and regional movements between areas with different malaria risks have three main consequences for the transmission and epidemiology of the disease:

i) individuals from low malaria risk regions traveling to high risk regions are particularly susceptible to disease because they lack well-developed immune responses. For example, increased rates of disease have been observed among migrants from low risk regions when they moved to highly endemic areas of Ethiopia, Indonesia, and Brazil.[3,25] If these individuals return home they may also transport malaria parasites back to their region of origin if it is receptive to transmission, and this has been shown to contribute significantly to local ongoing transmission in Zanzibar.[20]
ii) Individuals from high risk regions traveling to low risk regions may carry parasites with them, potentially sparking outbreaks and renewed or maintained malaria transmission.