Chapter 8
Geographic Medicine

Abstract This chapter highlights a sub-discipline of medicine, known as geographic medicine, to describe how human movements contribute to the transmission of parasites on spatial scales that exceed the limits of its natural habitat. Traditionally, public health programs have focused on the health of populations, whereas the practice of medicine has focused on the health of individuals. It should be noted, however, that the population health management owes much to the effective delivery of clinical care. This chapter demonstrates how public health is intimately linked to patient care through human movement. Nearly a century ago, people typically did not develop a disease where it is contracted or even close to that place. Today, daily travel is a common way of life in modern metropolitan areas. Large, localized mosquito populations in areas that people visit regularly may be both reservoirs and hubs of infection, even if people only pass through those locations briefly. By examining of the role of human movement across different scales, this chapter examines how public health communities can use information on pathogen transmission to increase the effectiveness of disease prevention programs and clinical care.

Keywords Geographic medicine • Human movement • Vector-borne diseases • Pathogen transmission • Globalization • Mass air transportation • Public health • Clinical care

8.1 Introduction

In 2008, the United States' Institute of Medicine convened an Expert Committee on the U.S. Commitment to Global Health and reaffirmed the notion that local health and local health care are linked to sources of disease and disability occurring elsewhere in the world [1]:

> Global health is the goal of improving health for all people in all nations by promoting wellness and eliminating avoidable diseases, disabilities, and deaths. It can be attained by combining clinical care at the level of the individual person with population-based measures to promote health and prevent disease. This ambitious endeavor calls for an understanding of health determinants, practices, and solutions, as well as basic and applied research concerning risk factors, disease, and disability.

Traditionally, public health has focused on the health of populations, whereas the practice of medicine has focused on the health of individuals. However, it should be

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noted that the population health management owes much to the effective delivery of clinical care and how medical activities affect it. In 2013, an entire issue of the *New England Journal of Medicine* was devoted to the problems and solutions of global health. In its Introduction, the editors wrote [2]:

> Diseases of global importance, such as injuries, noncommunicable diseases, and mental health, can be partitioned according to their differential geographic and temporal effects… Global forces such as globalization and climate change, as well as personal behavior involving risk factors such as tobacco use, excessive alcohol consumption, and poor diet, affect health in all countries.

The last three chapters of this book will illustrate the importance of geography in the practice of medicine, both on a local and global scale. The current chapter will highlight the role of geographic forces in the field of travel medicine (also known as geographic medicine) and emphasize the role of geographic knowledge and thought in a study of disease that views humans has vectors and hosts. Chapter 9 will introduce a relatively new discipline, called geospatial medicine, that utilizes the advances in geospatial data and technology to uncover the genetic, social, and environmental effects of disease as it occurs throughout human development. This is an exciting new field in which there is a tremendous potential for geographers to take center stage in answering some of the hard research questions that scientists have been grappling with for a long time. Lastly, Chap. 10 puts the finishing touches on the new portrait of medical geography that we have been painting, and frames it in a more centralized role on the national stage of the U.S. health care reform. A main objective of this book is to present a new model of patient care that emphasizes the patient's geographic and medical history, against the backdrop of contemporary globalization, while taking advantage of the current advances in geospatial data and technologies.

The current chapter will describe the main principles of travel medicine, and emphasize how human movements contribute to the transmission of parasites on spatial scales that exceed the limits of its natural habitat. Studies have shown that the ability to identify the sources (origins) and sinks (destinations) of imported infections due to human travel and locating the high-risk sites of parasite importation could greatly improve the control and prevention programs [3, 4]. For instance, a group of researchers have combined mobile phone data with a high-resolution malaria prevalence map to analyze the regional travel patterns of nearly 15 million individuals over the course of a year in Kenya, in the context of parasitic dispersals. In this way, they were able to identify and map the sources and sinks of human and parasite travel in this country (Fig. 8.1) [5].

To describe the challenges of travel medicine on human terms – in 2013, an estimated 1.1 billion travelers crossed international borders, including an estimated 28.5 million U.S. travelers [6, 7]. An increase in the number of international travelers and local commuters has caused a surge of global and regional epidemics in the past several decades [8]. Travel-related risks include infections from food, vectors, and bodily fluids. Most travelers (20–70 %) report health problems while traveling, but many do not seek pre-travel advice – such as vaccinations, prophylactics, and therapeutic medications [9, 10]. Moreover, the risk of travel-related diseases is 2.3 times higher in those with an underlying medical conditions than in health individuals [10]. Given the unique health situations of travelers, there is a need for better characterization

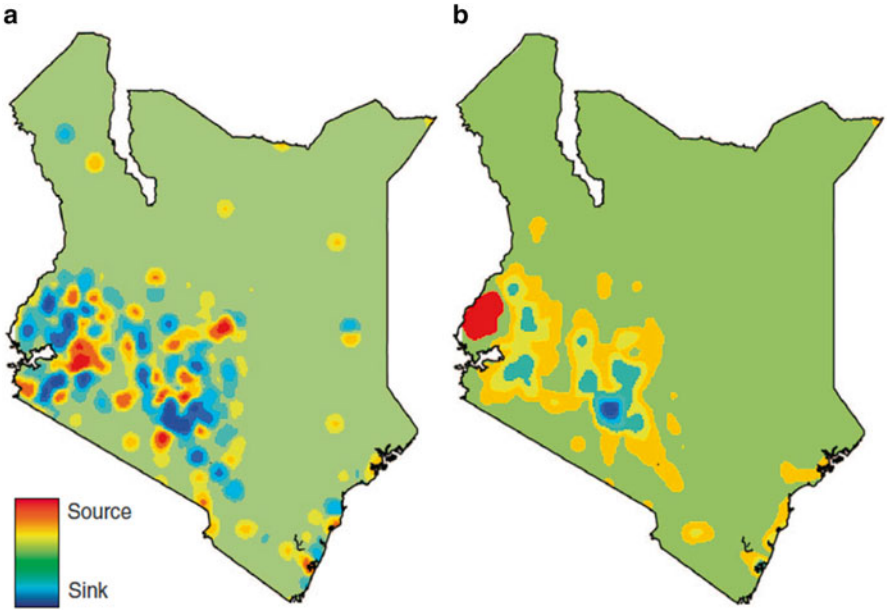

Fig. 8.1 Sources and sinks of people (**a**) and parasites (**b**). Kernel density maps showing ranked sources (*red*) and sinks (*blue*) of human travel and total parasite movement in Kenya, where each settlement was designated as a relative source or sink based on yearly estimates (From: Figure 3 in Wesolowski et al. [5])

of the geographical and environmental risk factors underlying travel-related illnesses. To address these concerns, this chapter describes how human travelers who are infected can serve as an important route for the transmission of the virus from their place of origin to their place of destination. By understanding the effects of human movement on disease transmission, researchers can appropriately identify high-risk areas for effective intervention and control.

8.2 Importance of Human Movements in Disease Transmission

Historically, epidemiologists have viewed human movement from two main perspective. The first perspective is from that of the populations of susceptible hosts moving into high-risk areas. The second perspective is from that of populations of infected hosts moving into susceptible populations. Movements of infected hosts across different spatial scales affect pathogen transmission in a variety of ways. Noted historian and geographer R. Mansell Prothero published one of the first studies describing the role of human movements in epidemiology based on his experience in Africa, in 1977. Drawing on the geographic literature concerning diffusion and migration processes, he discussed the relevance of these movement patterns to public health in his seminal paper published in the *International Journal of Epidemiology*.

He carefully outlined the differences between circulatory and migratory movements and categorized these movements by their spatial scale (i.e., a rural-urban gradient) and temporal scale (i.e., the time and timing of displacements). Circulatory movements are those in which the individuals return home after some period, and migratory movements are those which usually result in permanent changes of residence.

Prothero's argument was that knowledge of the nature of these movements would help inform the public's understanding of the incidence and prevalence of disease on a population level and provide informed options for control [11]. For instance, seasonal migratory movements from one rural area to another for agriculture could potentially expose individuals to different areas where the risk of African trypanosomiasis, or malaria, is high [12]. At broad spatial scales (e.g., national, international), individual movements can drive pathogen introduction and reintroduction. For example, the global spread of dengue virus via shipping routes was characterized by periodic, large, spatial displacements. Globalization and mass air transportation have changed the transmission of pathogens by dramatically shortening the time required to travel around the earth. At finer scales (e.g., regional, urban-rural, intra-urban), movement associated with work, recreation, and transient migration into high-risk areas not only lead to individual infection, but also contribute to local transmission when infected hosts return home and infect other individuals (Fig. 8.2) [13].

Indeed, vector-borne diseases place an enormous burden on public health and require efficient control strategies that are developed through an understanding of the origin (or sources) of infections and the relative importance of human movement at different scales. A number of social and environmental factors – such as human population density, regional settlement patterns, population movements, precipitation, and other weather-related factors – contribute to local and regional transmission dynamics [14]. Human movement – which determines exposure to vectors – is a key aspect of vector ecology that is poorly understood. This is due to the variations in exposure based on individual host movement that can strongly influence the pathogen's transmission dynamics [15].

The types of movement most relevant for exposure will depend on site-specific differences, the ecology of the arthropod vector, human behavior, and the relative scale of host and vector movement. For instance – although fine-scale host movements are not important to pathogens transmitted by vectors that are able to move long distances in search of a host – these fine-scale host movements are very important for pathogens transmitted by sessile vectors. *Aedes aegypti* is the principal vector of dengue virus. It bites during the day, disperses only short distances, and is heterogeneously distributed within urban areas. Humans, on the other hand, move frequently and allocate different amounts of time to multiple locations on a regular basis. Not only does this influence the individual risk of infection with dengue virus but it also influences overall patterns of transmission [16]. In addition, commuting and non-commuting patients have different diffusion patterns and determinants in a dengue epidemic. Non-commuters (e.g., elderly adults and housewives) may initiate a local epidemic, whereas commuters carrying the virus to geographically distant areas can cause a large-scale epidemic [17].

Dengue is a global threat and is endemic or epidemic in almost every country located in the tropics (Fig. 8.3). While new tools (such as vaccines, antiviral drugs

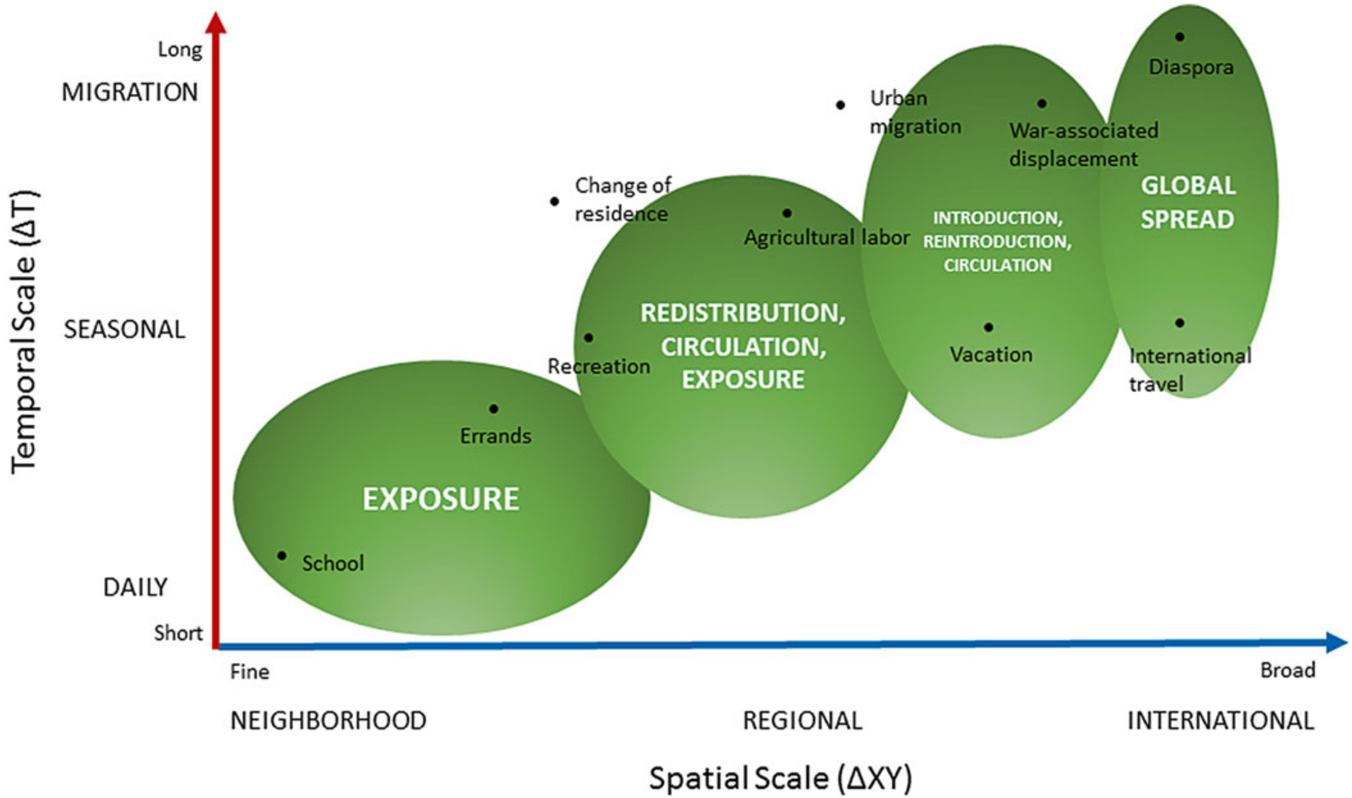

Fig. 8.2 A framework for human movements and their relevance to vector-borne pathogen transmission. Movements are characterized in terms of their spatial and temporal scale, which are defined in terms of physical displacement (ΔXY) and time spent (ΔT, frequency and duration). Generally, movements of greater spatial displacement involve more time (Adapted from: Figure 1 in Stoddard et al. [15])

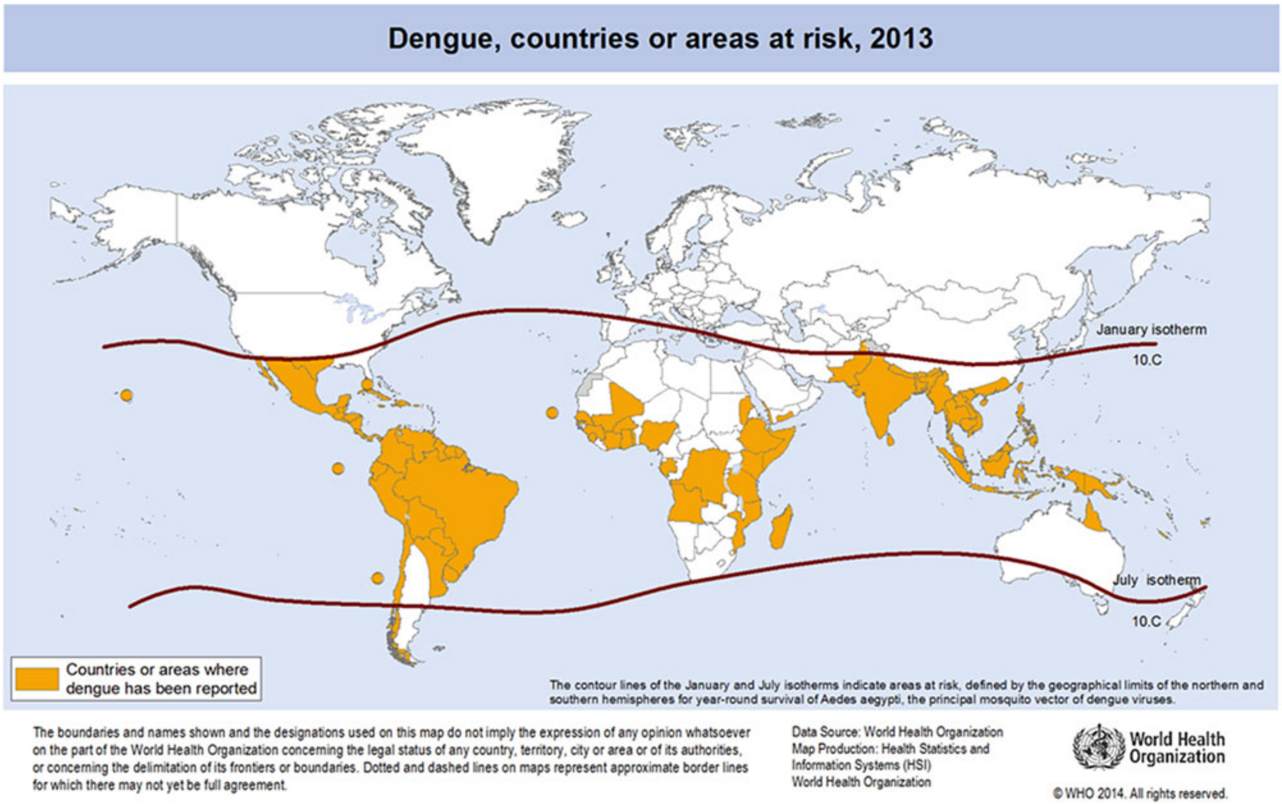

Fig. 8.3 Counties and areas at risk of dengue transmission, 2008 (Source: World Health Organization Map Production: Health Systems and Information Systems (HSI). http://gamapserver.who.int/mapLibrary/Files/Maps/Global_DengueTransmission_ITHRiskMap.png)

and improved diagnostics) are being developed, better use should be made of the interventions that are currently available. Along with comprehensive tracking of commuting cases, the concomitant rapid notification and diagnosis of non-commuting cases can enable the appropriate interventions and faster response times, thus preventing subsequent large-scale epidemics.

8.3 Geographic Considerations in Human Movement

As illustrated in the previous sections of this chapter, human movement is a largely ignored variable in the study and diagnosis of pathogen exposures. There are few, if any, well-established clinical guidelines that utilize a person's place history in the diagnosis of infected individuals, despite the fact that disease management protocols can be made more effective and efficient by targeting the sources or agents of transmission. The study of human movement is critical to identifying high-risk factors (e.g., host-preferences) because these factors are always conditioned by exposure rates which are, in turn, closely related to variations in human movement and behavior.

Although geographical movement is becoming increasing easy to measure through advanced geospatial technologies, a patient's movements and place history have been largely ignored by the medical community. Quantifying and describing human movements provides valuable information necessary to predict disease outbreaks and to evaluate control alternatives to halt epidemics [18–20]. In addition, the ability to apply this knowledge to a variety of diseases creates an opportunity to identify common areas where infection occurs across multiple diseases and to leverage public health programs to target the most important locations that serve as sources for more than one disease. By examining of the role of human movement across different scales, public health communities can use this valuable information on pathogen transmission to increase the effectiveness of disease prevention programs. As transmission rates are reduced through intervention efforts, scientists can expect the importance of heterogeneity in exposure to increase and play an even more important role in pathogen persistence. Therefore, characterization of human and population movements can facilitate not only the elimination of disease, but also help to prevent its return [15].

Key considerations in the analysis of human movement patterns include, but are not limited to: spatial scale, the type and periodicity of movement, and the time period of observation. Spatial scale refers to the geographical extent of the pathogen and the spatial interpretation of the data. The geographical extent of the pathogen and its transmission can be determined by the disease dynamic – i.e., the spread of a pathogen to new geographical areas versus a sustained transmission at a given location. If the transmission is local, then the relevant movements will be those placing the susceptible hosts in high risk locations at times when infection risk is high. Assumptions regarding the importance of movements should be made with care because heterogeneity in exposure can have a dramatic effect on infection risk.

The type of movement refers to what the researcher is aiming to measure. For instance, is the study interested in the sites where individuals spend their time on a regular basis (high spatial and temporal resolution) or when they are traveling outside of their home city? What is the value of travel information (outside of an urban area) that specifies exactly where people go? Are specific routes important, or should only destinations be considered? These specific details will depend on the nature of the questions, systems, and resources and methods involved for measuring movements.

Finally, the time period of observation is concerned with how long to observe individual movements for. The correct answer will depend on the questions being asked and available resources. In the case of dengue, infection can occur up to 2 weeks prior to the manifestation of symptoms. For a retrospective study, 14–15 days would be an appropriate observation period. Conversely, in a prospective study, the length of the observation period will depend on the relative importance of rare movements. Studies of human movements in developed societies reveal markedly regular patterns, especially during the work-week [19, 21, 22]. Additionally, there may be significant instability in movements on weekends or at other times (e.g., vacations). For regular movements during the work week, at least 2 weeks of observation are desired. For more variable movements/times, longer observation periods will be necessary.

8.4 Linking the Global to the Local Through Mobility

Over the last century, human civilizations and urbanization have witnessed a huge increase in mobility and population growth. The combined effect of these factors means that, despite great improvements in hygiene, sanitation and vector control, the containment of disease remains one of the biggest challenges of our modern contemporary society. The importance of increased human mobility in disease transmission cannot be under-stated. On national and global scales, the airline transport network has played a key role in the global dissemination of influenza and SARS [23]. In addition, migrants, tourists, and commercial travelers also have a significant influence on the spread of HIV [24]. On a local scale, human movements in metropolitan areas are frequent and extensive, but are often composed of highly structured commuting patterns between the home and places of employment, education, or business. The ability to quantify human movement and its effects are vital in the ongoing development of strategies to eradicate vector-borne diseases (such as dengue) from urban centers [25].

Using a meta-population analysis where mobile humans connect with static mosquito subpopulations in a very structured pattern, a group of researchers found that, due to frequency dependent biting, infection incidence in the human and mosquito populations is independent of the duration of contact [26]. The researchers hypothesize that, since the biting rate is frequency dependent (and independent of the density of the human population), a mosquito will bite the same number of people per day. In addition, their modeled results indicate that people who travel regularly to areas with large mosquito populations form a high-risk group, and have a relatively high level of infection compared to people that travel regularly to patches with small mosquito populations. Furthermore, extensive variation in human movement patterns causes the number of interactions between human and mosquito populations to increase. More variable human movements increases the likelihood that people will carry the infection from these highly infested areas to mosquito subpopulations where the pathogen has died out. Therefore, a large mosquito population in a frequently visited area may be sufficient to ensure infection is endemic, even if there are relatively few mosquitoes elsewhere. When people do not vary their travel patterns very much and there is no direct connectivity between mosquito populations, the transit corridor can significantly enhance disease persistence by acting as a reservoir and hub. If people vary the areas they visit even occasionally, the effect of the transit corridor is overridden [26, 27].

Mosquito and human movements become even more important as remote rural villages are connected to each other by mass transportation networks. Nearly a century ago, it was observed that people do not develop a disease where it is contracted or even close to that place [28]. Today, widespread mass transportation makes that observation even more relevant. The incidence and persistence of vector-borne diseases on relatively small spatial scales may be strongly influenced by infectious humans who remain mobile because the infection is mild or silent. Increased human movement on a local scale may be a key factor behind increased incidence of vector-borne diseases.

In modern metropolitan areas, daily travel is a common way of life. Distant subpopulations of mosquitoes may be connected by this daily movement. Large, localized mosquito populations in areas that people visit regularly may be both reservoirs and hubs of infection, even if people only pass through those locations briefly. This implies that surveillance with the goal of controlling vector-borne disease may be a much greater challenge than originally anticipated.

Ultimately, successful public health intervention must focus on both hosts and vectors. Large mosquito populations that are also visited by a large fraction of the human population need to be identified. It is vital to employ surveillance strategies that reveal the variability in the distribution of mosquitoes and target areas where the mosquito population is significant and human movement is extensive. Further study of networks formed by human movement in urban areas are need, and cell phone records are one potential source of such detailed information [19].

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