REVIEW

New digital technologies for the surveillance of infectious diseases at mass gathering events

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Abstract

Outbreaks of infectious diseases at mass gatherings can strain the health system of the host region and pose a threat to local and global health. In addition to strengthening existing surveillance systems, most host nations also use novel technologies to assess disease risk and augment traditional surveillance approaches. We review novel approaches to disease surveillance using the Internet, mobile phone applications, and wireless sensor networks. These novel approaches to disease surveillance can result in prompt detection.

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The WHO defines mass gatherings as congregations that are 'sufficient to strain the planning and response resources of the community, state or nation hosting the event' [1]. Humans have long gathered for religious and sporting events, and disease outbreaks have been recorded at such gatherings from as early as AD 632 [2]. The scale of mass gatherings and the close proximity and overcrowding of individuals at these events increases the risk for importation, local spread, and subsequent exportation of infectious diseases. Outbreaks at mass gatherings including vaccine-preventable (e.g. meningitis [3] and measles [4]) and non vaccine-preventable (e.g. Legionnaires [5] and shigellosis [6]) infectious diseases have been documented.

To prepare for communicable disease events at mass gatherings, host countries implement risk assessments to identify, analyse and evaluate the likelihood of various infectious diseases and their potential public health impacts [2]. Additionally, communication and collaboration between public health institutions within the host country, as well as between home institutions in participants' countries of origin, are important for adequate risk assessment and planning for international mass gatherings. Preventive measures such as vaccinations, anticipatory surveillance [7], and enhanced surveillance during and after the event are useful for preventing and quickly identifying disease threats either at the site of the gathering or elsewhere in the world. The intensity of risk assessment and surveillance activities depends in part on the duration of the event and the number of participants and their activities [8].

Decreased cost and increased ease and speed of global travel have increased the number of attendees at these events [2,9] and expanded the geographic radius from which the attendees travel, leading to the potential for larger and extensive spread of emerging outbreaks [10]. Fortunately, these changes have dovetailed with improvements in mobile and digital technology, offering greater opportunities for and augmentation of traditional surveillance systems during major mass gatherings. These technologies include Internet-based systems, mobile phone applications, wireless sensor networks and syndromic surveillance systems. Because health and technological infrastructures are not consistent globally across regions, the utility of these diverse technologies is partially dependent on the geographic location of the gathering.

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This review describes the digital technologies that have emerged to help detect and predict disease outbreaks at some of the world's largest and most popular mass gatherings. We focus on the Hajj, the Olympics, Athletic World Cup gatherings (specifically, the Fédération Internationale de Football Association (FIFA) World Cup and Rugby World Cup), and other mass gathering events.

Major religious gatherings

The Kumbh Mela is a Hindu religious gathering that occurs every 3 years in one of four locations (Haridwar, Allahabad, Nashik and Ujjain) and has involved more than one hundred million people [10–14]. The event, which usually lasts for about a month and a half, requires careful planning and disease-risk assessment in order to detect and control infectious disease outbreaks. Kumbh Mela gatherings have been associated with major outbreaks of cholera [15]. Telemedicine—the use of electronic resources in the exchange and transmission of medical knowledge and data- was credited with aiding to avert a possible cholera epidemic at the 2001 gathering [16]. Researchers have also used novel technologies such as Apple iPads to geo-locate pilgrims visiting hospitals during Kumbh Mela [11,12]; however, most of the public health success can be attributed to sanitation, and the sufficient availability of hospitals, doctors and medical staff. In addition, thousands of sweepers are charged with the collection of both faecal material and other rubbish estimated at 40 to 50 tons each day [13,17]. Such sanitation practices help to limit cases of diarrhoea, *Escherichia coli*, cholera and other infections.

The Hajj, which draws about three million people to Mecca from all over the globe annually, is another major religious gathering [18–21]. Muslims also gather in Mecca year-round to perform a 'minor' pilgrimage called Umrah. The month of Ramadan is the peak time for performing Umrah and the number of participants can be as high as during the Hajj. Given both the magnitude of these events, and the geographic diversity represented among the pilgrims, a broad range of infectious diseases can be introduced. Respiratory infections occur frequently among pilgrims returning from the Hajj [2,18,22]. In addition to rhinovirus, risk for contracting tuberculosis is as high as 10% [2,23]. The vast majority of pilgrims travel from low-income countries where tuberculosis is endemic, and though they may not be symptomatic upon arrival, the disease may be reactivated by the physical stress of the pilgrimage [2]. This said, the leading cause of hospitalization during Hajj is pneumonia, which may be caused by a wide array of common infectious pathogens such as *Streptococcus pneumoniae* [24]. However, evidence suggests that the novel Middle East respiratory syndrome coronavirus, which was first discovered in 2012, may also present clinically as pneumonia [25]. Following a large outbreak of Middle East respiratory syndrome in spring 2014, the Kingdom of Saudi Arabia has been particularly conscientious about surveillance during the 2014 Hajj season [2,22,24]. In addition to infectious disease surveillance, a number of novel digital technologies have emerged in recent years that can be useful for a variety of other problems that commonly arise during the Hajj, including crowd control to avoid trampling and identification of pilgrims who are lost, dead, or injured [2,20,23].

Boudhir et al. propose one such versatile solution that can use wireless sensor networks (WSN) and body sensor networks (BSN) technologies to locate pilgrims who are critically ill [26]. A WSN consists of a large number of nodes that communicate with each other to sense physical and environmental conditions. A BSN is a highly specialized application of WSN in which on-body sensors monitor an individual's biometrics (e.g. heart rate, oxygen saturation, blood pressure, etc.). When combined, these two networks can be used to locate pilgrims who are ill and send ambulatory services to their coordinates if necessary. Similarly, Mitchell et al. outline a system that can track pilgrims using radio frequency identification (RFID) technology [20]. This particular solution also offers a mobile application for pilgrims with smartphones, which can be used not only to further supplement the RFID location data but also to call for an ambulance in the case of an emergency.

While these multipurpose technologies still remain largely conceptual, the Kingdom of Saudi Arabia has actively invested in and successfully enacted two major digital surveillance systems specifically designed for infectious diseases among pilgrims. When swine flu was declared a global pandemic in 2009, the Saudi Ministry of Health (MOH) and US CDC launched the Hajj Mobile Disease Surveillance System (Hajj-MDSS). During the course of the initiative, the Hajj-MDSS was used for the rapid detection of various infectious diseases among pilgrims (influenza and others), enabling informed decision-making for disease control and prevention [10,19,27].

More recently, the Kingdom of Saudi Arabia implemented a Healthcare Electronic Surveillance Network (HESN), which is a web-based system similar to Hajj-MDSS that enables mobile monitoring of cardiovascular, gastrointestinal, respiratory, skin and eye/ear diagnoses [22]. The system aggregates data from a variety of end-user healthcare practitioners, including not only hospital and clinic staff but also ambulatory paramedics; this information is made readily available for semi-automated analysis, which can then be used for prompt decision-making [2]. Al-Tawfiq and Memish found that the HESN proved to be very effective during the 2013 Hajj season for the purposes of