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 disease surveillance and monitoring among pilgrims due to the rapidity of data transmission from practitioners to decision-makers [22].

Olympics

Surveillance systems for the Olympic Games have varied substantially over the years. A number of factors likely contribute to this variability, including season (summer versus winter games), location (climate, endemic diseases and existing surveillance systems and capacities), and current global disease trends.

The Olympics committee and host city have increasingly emphasized disease prevention and surveillance as a focus of their planning responsibilities. The Olympics draw millions of people from countries around the world to watch and participate in sporting events. The city where the games are hosted becomes an ideal environment for the spread of any number of imported or endemic communicable diseases. Although there have been few major outbreaks at past Olympics, a number of events have highlighted the need for vigilance at this mass gathering. In 1991, at a Special Olympics game in Minneapolis-St Paul, an outbreak of measles stemmed from an Argentinian athlete with the disease [28]. In 2010, 82 cases of measles arose in British Columbia following three primary cases who were exposed in downtown Vancouver during the winter Olympics [29].

Digital technology has supplemented traditional disease surveillance systems for Olympic Games in recent years. One of the earliest digital tools was the Real-Time Outbreak and Disease Surveillance system, implemented for the 2002 Salt Lake City winter games [30]. This automated system aggregated data from urgent-care centres and emergency departments, provided visual plots and maps, and was set to trigger an alert if it found unusual disease activity. Two alerts were elicited following high levels of respiratory disease, but health officials determined that the number of cases was consistent with seasonal flu projections.

In preparation for disease surveillance for the 2008 Beijing summer Olympics, traditional health services and communications in Beijing were strengthened, but new digital technology was not prioritized [31]. There was, however, an effort to predict in advance the risks of various disease outbreaks using the GeoSentinel Surveillance Network. This system maintains the largest existing database of travel-related illnesses with geographic information and was used to assess which diseases were most common among travellers to China [32].

Big data for disease surveillance was introduced in preparation for the Vancouver 2010 winter Olympics. In addition to traditional surveillance systems [33], an integrated system was developed that combined knowledge of worldwide air traffic patterns with Web-based global surveillance of infectious diseases to anticipate the threat of disease outbreaks leading up to and during the Olympics [34]. HealthMap [35], an online disease-monitoring tool, displayed these results on an interactive map. Canadian health officials monitored these daily reports and were prepared to investigate any identified threats.

The surveillance strategy used during the London 2012 summer Olympics was similar to that used in Vancouver. Existing domestic health systems were strengthened, while international surveillance was enhanced to combine official reports with real-time open-source technologies [36]. Improved technologies were implemented to increase the speed of communication within the surveillance system, allowing for daily summary reports of findings as well as immediate notification to the national coordination centre in the event of a potentially serious threat [37]. Additionally, the Health Protection Agency monitored social media sources to identify health rumours, and they responded by publically conveying reassurance and communicating accurate information [37]. Fortunately, no major public health incidents occurred during the London Olympics, but officials found that rumour management had become a critical surveillance responsibility in the age of prolific social media [37].

Little documentation is available regarding disease surveillance at the 2014 Sochi winter Olympics; this may be because the documentation has not yet been released or has only been released so far in Russian. The same HealthMap platform developed for Vancouver and London was also available during the 2014 winter Olympics [38], although it is unclear if this source was used by the official surveillance team.

Athletic World Cup events

While the Olympic events are the best-known international sport-related mass gatherings, many sports federations hold World Cup games with rotating host cities. The variety of locations and host countries contributes to the diversity of infectious disease concerns and opportunities to use novel surveillance technologies.

To monitor the health impacts of the 1998 FIFA World Cup, France used electronic sentinel disease surveillance to monitor in real time health events captured by five sentinel networks that included general practitioners, emergency departments and community health services [39]. Although no epidemiological impact on the general community was identified, this effort demonstrates a relatively early adoption of networking data sources for mass gathering surveillance.

For the 2003 Rugby World Cup in Australia, improvements in data processing were included in an automated syndromic surveillance system—an approach that relies on indicators such as disease symptoms and behaviour patterns that may signify illness before laboratory confirmation of disease—to support the processing and analysis of a broader range of data [40]. Triage information was processed by a system using an automated naive Bayes text categorization technique to produce daily summaries that analysts could then use to identify unusual clustering of symptoms.

During the 2006 FIFA World Cup, Germany moved beyond surveillance of medical records to include review of domestic and international media sources [41]. Researchers searched for articles using 14 keywords (e.g. epidemic or bacteria) for additional information on public health threats.

Brazil adopted many new technologies to support its disease surveillance efforts throughout the 2014 World Cup. The Healthy Cup application for Android and iPhone platforms used the adoption of smart phones and apps as well as crowdsourcing to expand their infectious disease surveillance efforts beyond earlier efforts. The app provided health information including locations of health providers and disease prevention advice. Users were asked to provide a daily health status so that researchers could view the aggregated reports and identify any significant changes at the population level [42].

In addition to the host countries, participating countries or health organizations overseeing populations who may travel to these events often develop their own plans for epidemic intelligence work. For example, 11 teams from EU countries participated in the 2010 FIFA World Cup held in South Africa. The European Centre for Disease Prevention and Control (ECDC) developed a plan for enhanced epidemic intelligence activities that included expanding their regular information sources to include specifically designed queries to MediSys, a monitoring system that collects information from the Internet on potential public health threats [43]. This automated system identifies media reports on relevant topics in dozens of languages, categorizes the content of the articles, and clusters them to identify top stories [44]. MediSys is one of numerous systems analysing Internet data to provide international event-based biosurveillance [45].

Before the 2010 FIFA World Cup, 13 years of data on patients returning from destinations in sub-Saharan Africa were extracted from the GeoSentinel Surveillance Network and reviewed to inform pre-travel advice to World Cup attendants [46]. Whereas the database itself reflects traditional surveillance work, GeoSentinel's use of web-based technology to collect reports from member sites and its earlier collaboration with HealthMap to support rapid mapping of case data reflects the way traditional surveillance efforts are adopting new technologies to expand their capabilities.

Smaller mass gatherings

In addition to the aforementioned global mass gatherings, there are other athletic, music and technology events that are worth mentioning. As previously noted, traditional public health practices for disease prevention and control have been used in combination with Internet-based surveillance systems during sporting events. For example, during the June 2012 European Football Championship, which brought together more than 8 million people, a combination of existing indicator-based surveillance systems and Internet-based technologies, such as the aforementioned MediSys electronic health records system, the Global Public Health Intelligence Network (GPHIN) and the communicable disease network of EpiNorth, were used by the ECDC for screening and searching the web for reports of disease [47]. Using these validated and non-validated sources, the ECDC produced daily disease bulletins for local public health practitioners and the WHO. No significant public health threats were noted during the championship.

Additionally, Internet-based methods that have been used for population-level surveillance of infectious diseases have been retrospectively evaluated for use in disease surveillance during mass gatherings. Researchers extracted Twitter postings and Bing search queries during and after nine major music festivals held in the United Kingdom in addition to the Hajj [48]. These Internet-based data sources showed some indication of disease symptoms in two of the nine festivals.

Syndromic surveillance now often complements traditional surveillance and Internet-based tools for monitoring disease outbreaks at mass gatherings [10,49–51]. This type of system is timelier than traditional surveillance and widely used for situational awareness. Syndromic surveillance systems played a role in mass gathering plans for recent Super Bowl games, with STARS (Syndromic Tracking and Reporting System), BioDefend and ESSENCE (Electronic Surveillance System for the Early Notification of Community-based Epidemics) systems used during the 2001, 2005 and 2007 games, respectively [52,53].

Routine automated syndromic surveillance provided by a real-time emergency department surveillance system was also used in combination with data gathered by field public health officials, daily monitoring of media, and first aid case reports during a music festival in Tamworth Country, Australia [51]. No outbreaks of communicable diseases were detected. In addition, during the 2010 World Exposition in Shanghai, China, which lasted 6 months and included a population of 70 million, a combination of syndromic (school absenteeism), Internet-based, emergency and notifiable disease surveillance systems were used [54]. Table 1 lists the technologies discussed in this paper.

TABLE 1. Brief description of digital technology tools

Digital technologies and systems	Description
Bing	Internet search engine (http://www.bing.com)
BioDefend	Syndromic surveillance system for monitoring bioterrorism and infectious disease threats
Electronic Surveillance System for the Early Notification of Community-based Epidemics (ESSENCE)	Syndromic surveillance system based on electronic emergency department data for early detection of public health events
EpiNorth	A project that aimed to improve communicable disease surveillance in Europe (http://www.epinorth.org)
GeoSentinel Surveillance Network	Network of clinics that monitor travel-related illnesses (http://www.istm.org/geosentinel)
Global Public Health Intelligence Network (GPHIN)	Internet-based system that monitors public health threats using data from news reports and websites
Hajj Mobile Disease Surveillance System (Hajj-MDSS)	A mobile-based system implemented in 2009 for monitoring disease threats during the Hajj
Healthcare Electronic Surveillance Network (HESN)	Web-based system developed for communicable disease surveillance, and outbreak and public health resource management
HealthMap	Internet-based site for infectious disease surveillance based on the extraction of data from a variety of sources (www.healthmap.org)
Healthy Cup Application	Android and iPhone application used during the 2014 FIFA World Cup for surveillance and prevention of disease
MediSys	A system that collects information from the Internet on potential public health threats
Radio frequency identification (RFID) technology	Wireless system composed of tags and readers. Readers emit radio waves and receive signals from tags
Real-Time Outbreak and Disease Surveillance (RODS)	Open source software for collection and analysis of disease surveillance data (http://openrods.sourceforge.net)
Syndromic Tracking and Reporting System (STARS)	Syndromic surveillance system for tracking bioterrorism and infectious disease threats using hospital emergency department data
Twitter	A social media micro-blog site (www.twitter.com)
Wireless and Body Sensor Networks	Wearable systems with wireless transmission

Conclusions

The novel technologies discussed in this review are typically used to augment traditional public health surveillance approaches by enabling the documentation of health events, risks and services in a manner that can guide disease event response. The value of these technologies lies in their timeliness, sensitivity, specificity, predictive value and accessibility. While traditional approaches such as contact tracing can be extremely challenging during outbreaks at large mass gatherings, systems based on these technologies can aid in early detection and help facilitate a prompt response.

In the future, emerging diagnostic tools can be useful during mass gatherings. For example, Foldscope [55], a low-cost portable microscope developed combining origami and principles of optical design, could be easily imported into regions with limited resources. Although currently in an exploratory phase, such technologies lend promise to the future of disease surveillance and detection. Additionally, rapid point-of-care diagnostic tests for both bacterial and viral infections can be useful during mass gatherings. There are several of these technologies on the market (and in development) with varying sensitivity and speed of diagnosis [56]. Accessibility of these tests to clinicians can aid in rapid diagnosis of existing and emerging infectious diseases.

The propagation of an infectious agent (such as Ebola virus or Middle East respiratory syndrome coronavirus) during a mass gathering can strain the health system of the host region and pose a threat to local and global health. Adequate planning, public health surveillance and communication between health practitioners and the general public are therefore important for the prevention and control of disease outbreaks.

Transparency declaration

The authors declare that they have no conflicts of interest.

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