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K.C. designed the content and flow of the paper. S.W. and J.G.W. collected the necessary information and data. S.W., J.G.W., G.C.P. and K.C. wrote the paper.

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The authors declare no competing interests.

How better pandemic and epidemic intelligence will prepare the world for future threats

A new approach to pandemic and epidemic intelligence is needed that includes modern approaches to surveillance and risk assessment, as well as improved trust and cooperation between stakeholders and society.

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Pandemic and epidemic threats constantly occur. Each month, the World Health Organization (WHO) identifies around 4,500 such public health signals globally. Once a public health event is confirmed, risk assessment, expanded surveillance, and intelligence gathering are needed to understand how the event is unfolding, what impact control measures are having, and how to prepare for different scenarios that might follow. The emergence of SARS-CoV-2 and the progression of the COVID-19 pandemic show the challenges in understanding how risks change during an emerging infectious-disease event.

Traditional surveillance approaches, such as monitoring the number of cases and deaths, are insufficient for the management of such a complex public health threat. The WHO has developed a new model for the surveillance of emerging threats, called 'pandemic and epidemic intelligence', that builds upon a range of traditional approaches[1] and non-traditional approaches[2–5]. The pandemic and epidemic intelligence approach must be scaled up to better anticipate and prepare for future threats.

Credit: traffic_analyzer / DigitalVision Vectors / Getty

Contemporary surveillance approaches

Most traditional public health surveillance systems are designed around a paradigm of counting the occurrence of disease, including human cases, hospitalized patients and positive laboratory diagnoses, pathogen genomes, and attributable deaths. Such approaches rely on stable case ascertainment over time and a robust baseline against which changes can be assessed. An outbreak is classically defined by changes in case incidence in the context of person, place or time. However, this paradigm is often not sufficient for the rapid detection of emerging infectious diseases, when early case numbers are small, where no historic baseline exists, or where diagnosis of cases is uncertain, perhaps due to lack of adequate testing. Nonetheless, such traditional surveillance systems are vital for tracking the epidemiological evolution of infectious-disease events.

There are newer approaches to surveillance, which should also be harnessed (Table 1). Since the mid-1990s, event-based surveillance has harnessed unstructured

Table 1 | Examples of traditional and modern approaches to pathogen surveillance

Approach	Surveillance technique
Traditional	Human patients who present at healthcare services
	Hospitalized patients
	Laboratory diagnoses
	Pathogen genome sequencing
	Mortality estimation
	On-the-ground investigations, including active case finding and contact tracing
Modern	Detection of signals of public health events from unstructured textual online information, including social media channels
	Data from sectors not routinely included in public health surveillance, such as animal health, occupational health and police reports
	Community reporting of cases, deaths or events among humans or animals
	Geospatial, remote-sensing and mobile-phone mobility data
	Crowdsourcing open-source case-based data
	Wearables and the Internet of Things

Table 2 | Current challenges in pandemic and epidemic intelligence

Challenge	Potential solution(s)
Data fragmentation	New taxonomies and ontologies are needed to enable diverse data to be connected directly or through federated data models
Difficulty accessing sources	New digital technologies can facilitate the analysis of data remotely, in whatever form they reside, while data custodians retain full control of their data
Licensing, ownership	Novel licensing and access models could make data insights available from copyrighted information when used for public-health and global-good purposes
Cyber security risks	Cyber security measures need to be strengthened for all public health surveillance systems and need to be incorporated into designs for interconnected data systems
Analysis challenges	Automation and artificial intelligence approaches can improve capacities to analyze large volumes of different data types
Increased computing requirements	Analyzing large quantities of highly complex data will require access to distributed computing services for public health institutions
Risk assessments will include more determining factors	Tools will be needed to assist human analysts in considering many determinants of risk, both quantitative and qualitative
Organizational challenges	Public health institutions will need to be organized to facilitate institution-wide inclusion in intelligence functions and the creation of intelligence teams
Requirement for a highly trained team with diverse specialties	An intelligence workforce will require topic-specific experts in human and animal health, social and behavioral sciences, environmental sciences and data science, among others

textual information, often available online, to detect unusual health events that may indicate potential outbreaks[6]. Systems for event-based surveillance contain limited epidemiological, clinical or laboratory diagnostic detail and perform with low specificity[7]. For example, during winter months, the number of media articles reporting clusters of respiratory disease syndromes increases, but these clusters may be not be linked or may be due to different pathogens. However, event-based surveillance systems have high sensitivity and are fast[7], which is a desirable feature for the detection of new and emerging events. Because event-based surveillance includes signals from both real public health events and false alerts, it must be coupled with on-the-ground verification by field epidemiologists.

Since the early 2000s, other surveillance approaches have been developed to allow surveillance to be conducted directly by community members, a process sometimes referred to as 'participatory surveillance'[8–11]. These surveillance approaches have the potential to collect community-based information about suspected occurrence or risk of emergence of disease in human populations, such as Ebola virus disease[11] and zoonotic influenza in wildlife and livestock[12]. These outbreaks may be missed by traditional surveillance systems, so community surveillance can provide early indications of the emergence of new events, even before patients interact with healthcare providers[12].

Assessing risk

Since 2017, the WHO has been developing its approaches to the detection and understanding of new and emerging public health risks. These approaches have been consolidated into a more expansive conceptualization of public health surveillance to which the new WHO Hub for Pandemic and Epidemic Intelligence ('WHO Pandemic Hub') is dedicated. This is an approach that combines information from traditional surveillance, event-based surveillance, participatory or community surveillance, and on-the-ground investigations, with contextual information, to generate an assessment of public health risk. Contextual information includes any information that improves interpretation, such as the composition of affected communities, travel patterns, geography and environment, animal populations, health systems capacities, deployment of medical countermeasures, and social factors, such as public sentiment about disease-control measures.

There are several advantages to this pandemic and epidemic intelligence approach. Because the output is an assessment of risk, it feeds more directly into decision-making for public health and government officials[7]. The approach leverages all available information, including data from non-health sectors and social media and other community-generated data. Innovations in data science enable the analysis of ever-larger quantities of data. Pandemic and epidemic intelligence is also useful for understanding how public health risks change over time and how they are modified by the use of medical countermeasures, the implementation of community-based control measures, the genetic evolution of pathogens, and other factors that vary over time.

Conducting effective pandemic and epidemic intelligence, however, is not straightforward (Table 2). Gathering, managing, analyzing and interpreting disparate information from the health sector and beyond is complex, in part because of data fragmentation, difficulties with accessing sources on a continuous basis, licensing, ownership and security restrictions, privacy and re-identification risks, and the inherent complexity of working with a wide range of different data types and formats. Other organizational, administrative and governance issues at national and local levels may also need to be addressed[13]. Specialized tools, such as those developed by the Epidemic Intelligence from Open Sources initiative (https://www.who.int/initiatives/eios), are in need of further development. Current risk-assessment methodologies (https://www.who.int/publications/i/item/rapid-risk-assessment-of-acute-public-health-events) are difficult to implement for events with complex geographical distributions or where an outbreak includes both humans and animals. The synthesis of structured and unstructured information is inherently a human-driven consensus approach that is highly dependent on the skills, experience, independence and availability of the specialists involved. The pandemic and epidemic intelligence approach requires a highly trained team with considerable experience and technical resources in a wide variety of technical areas.

Global trust architecture

The WHO Pandemic Hub has been established to accelerate capabilities for improved detection of and response to public health threats. At the heart of this vision is a new dynamic of global collaborative intelligence that pools the capacities of government institutions, non-governmental organizations, academic bodies, the private sector and civil society. Working together to build a stronger global trust architecture is critical: promoting transparency and sharing is more important than ever in a global context with growing challenges to data openness, reliability and trustworthiness. In recognition of the need for greater collaboration, the WHO Pandemic Hub office in Berlin, Germany, has been modeled in the style of a campus and loosely follows the approach of CERN, the European Organization for Nuclear Research, which explicitly promotes international, multi-disciplinary and multi-sectoral collaborations. The WHO Pandemic Hub has already embarked on new collaborative approaches, such as working with global health and other partners to collect data and analyze the global outbreak of monkeypox[14].

The WHO Pandemic Hub will strengthen traditional disease surveillance systems, integrate newer surveillance approaches, promote data transparency and sharing, and improve public health institutions' abilities to synthesize contextual information for risk assessment and decision-making. Being better prepared for future pandemics and epidemics will require focused effort to increase collaboration while we invest in our collective abilities to detect and understand public health risks. ❐

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