Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

Elsevier hereby grants permission to make all its COVID-19-related research that is available on the COVID-19 resource centre - including this research content - immediately available in PubMed Central and other publicly funded repositories, such as the WHO COVID database with rights for unrestricted research re-use and analyses in any form or by any means with acknowledgement of the original source. These permissions are granted for free by Elsevier for as long as the COVID-19 resource centre remains active.
Surveillance of Infectious Diseases

Norman Noah, London School of Hygiene and Tropical Medicine, London, United Kingdom

© 2021 Published by Elsevier Ltd.

Glossary

Case-fatality rate Number of persons dying of an infection divided by total number of persons with the disease. Thus, CFR of 5% means that 5 of 100 persons with the infection died. It is distinguished from "Mortality Rate" which measures the death rate in the whole population.

Endemic An infection continues in a country, though may vary in incidence at different times. Many enteroviruses, adenoviruses and respiratory viruses are endemic.

GUM clinics The term GenitoUrinary Medicine clinics is often used for special clinics for sexually transmitted infections (STIs).

Incidence The rate of new infections (number by population) in a given time – for example, 5 cases of influenza per 1000 per year. Good for short-term infections.

Outbreak and epidemic Most infectious disease epidemiologists do not distinguish between these terms and use them interchangeably. Generally, an outbreak is defined as a localized increase in cases, whereas an epidemic is more widespread, perhaps affecting a whole country.

Outbreak When an infection occurs at a frequency higher than expected for that time or place. It is basically an increased incidence which is usually unexpected. Two linked cases is also theoretically an outbreak.

Pandemic This term should be restricted to infections affecting many countries, and may extend virtually worldwide. SARS spared many countries and indeed some continents, but it was a pandemic. SARS-CoV-2 and AIDS undoubtedly caused pandemics.

Prevalence The number of infections at any one time in a given population, expressed as a rate. Good for chronic infections such as chronic hepatitis B or C and serological studies (e.g., prevalence of varicella antibody at age 15 in a given population is 95%).

Introduction

Surveillance is undoubtedly an essential – indeed critical – ingredient of any disease control program. It is used to paint a picture of the progress and overall burden of infection or disease, so that any preventive or therapeutic action can be measured as it advances. In this way, the impact of an infection, the effect of an intervention or health promotion strategy, health policy, planning, and delivery can be monitored. Surveillance is the ongoing and systematic collection of routine data which are then analyzed, interpreted, and acted upon. It is essentially a practical process, which nevertheless can be useful in other ways. Its main purpose is to analyze time trends – but these can include not simply fluctuations in overall numbers, but also changes in age and sex distributions, geographical locations, and even possibly, in some of the more sophisticated established surveillance systems, at-risk groups (such as particular social, ethnic and occupational groups). Surveillance is essential for evaluating the impact of an intervention, such as mass vaccination, on a population. It can also act as a fairly sensitive system for the early detection of outbreaks.

Essential Characteristics of Surveillance

The word ongoing in the description of surveillance helps to distinguish it from a survey, which is usually finite, tends to focus more on one or more groups of persons, and involves a questionnaire. Nevertheless, surveillance does not have to continue forever – when it is no longer useful, it should be stopped.

To be systematic and consistent are other important ingredients of surveillance. If reporting centers are not consistent in what they report, nor regular, the data they send in will be uninterpretable, and probably useless. Defining what needs to be reported, its frequency, and agreeing on the criteria for making a reportable diagnosis are necessary to make sense of the data.

Timeliness is another important ingredient of a surveillance system. This is especially the case with infection. It is particularly essential for the early recognition of outbreaks, but it is important also in evaluating the success or otherwise of programs to control the spread of an infection e.g., the effect of lockdown on coronavirus disease (COVID-19) on a population.

Representativeness is another important ingredient of a surveillance program. The program has to be representative of the effect of that infection on a population. This may not always be possible, and any biases and inconsistency in reporting has to be taken into account in interpreting the data.

Completeness is generally less important than representativeness, especially for relatively common infections. Completeness becomes important if or when the number of infections decreases, whether on its own or through a public health intervention. For some serious infections, completeness may also become important. Completeness is discussed in more detail later in this article.

The collection of routine data is another important characteristic of surveillance, especially with surveillance of laboratory infections. Generally, testing of samples is done for diagnosis, not primarily for surveillance. As laboratory testing is expensive, making further use of the results by contributing to surveillance makes for more efficient use of information, and the contribution to surveillance itself can
often justify further testing. Typing echoviruses or coxsackie viruses can seldom be justified on clinical grounds alone, but the
surveillance of serotypes can provide valuable information on the epidemiology of these viruses, their clinical characteristics,
seasonality, and age and sex distributions – and of course whether there has been an outbreak. Echovirus 4 for example tends to be rare,
fairly localized even within a country, but, when it occurs, it has a high aseptic meningitis rate, and causes a short and sharp autumn
outbreak. Echovirus 9 on the other hand is far more common, more widespread geographically when it causes an epidemic, more
benign, with a macular rash, and with meningitis not an especially common manifestation. The weekly patterns of some of these
viruses can provide clues on future resurgences. Echovirus 4 as stated, comes and goes in one season. In the autumn of 1974, a small
outbreak of echovirus 19 did not disappear entirely throughout the winter. A further and much larger outbreak in the autumn of 1975
was predictable, and occurred.

Although surveillance is essentially a practical exercise, this article attempts to show that surveillance can also be useful in
giving us clues about an infection, whether it be its natural history, etiology, severity, or outcome.

Collection of Data: Sources of Data in Surveillance of Viruses

Death Certification
In most developed and middle-income countries, deaths are certified primarily for legal reasons, but have proved to be an
important data source to use for surveillance. Clearly, they tend to be useful mainly for serious infections, and may suffer from
inaccuracies, but remain a useful basic data source. Diseases with a high mortality rate and a short duration of illness (the viral
hemorrhagic fevers for example) will obviously be better represented by death certification than those with a low mortality.
HIV/AIDS, before the era of HAART, had a high mortality but long periods of symptomless and symptomatic infection, so that
death certification data needed careful interpretation. It is well known that death certification standards of accuracy vary not only
from country to country, but also within countries. In England, in the early years of the HIV epidemic, it was shown that deaths in
single men had risen in number although AIDS was not mentioned on the death certificates. With influenza outbreaks there is
usually an increase in total mortality in the elderly otherwise unaccounted for. The reporting of deaths from SARS-CoV-2 both
within and between countries is also known to be inconsistent. Excess deaths have become a useful measure in estimating
mortality from influenza and SARS-CoV-2.

Laboratory reporting systems can sometimes be another useful source of information on mortality from infection.

Notifications
Surveillance systems such as statutory notification tend to be based mainly on clinical features. These can be very useful for
common diseases with distinctive clinical syndromes, such as measles and mumps. It is important however not to make a disease
notifiable unless there is a good reason for it: “good” reasons include a mass vaccination program (when surveillance is virtually
mandatory), any other mass control program, or serious diseases for which contact tracing, mass or close contact prophylaxis or
investigation into source is necessary. Serious less common viral infections such as poliomyelitis are notifiable in most countries.
This is because contact tracing and preventive measures can be taken. Broader clinical diagnoses, such as aseptic (viral) meningitis,
may on the face of it be less useful to notify, as it is usually impossible at the bedside to distinguish such causes of it as, for
example, the coxsackie B viruses, echoviruses, and mumps. Nevertheless, notification of aseptic meningitis can be useful because a
rapid rise in notified cases may need to be investigated further. Moreover, the timing of any epidemic may give a clue to etiology –
mumps meningitis tends to increase in spring and is usually accompanied by a concurrent outbreak of clinical mumps, while
enterovirus epidemics are more likely to occur in autumn.

Other Sources of Data
Specific general practitioner (GP) surveillance systems are useful in providing data of epidemiological value for common infec-
tions that are not notifiable, such as the common cold or chickenpox (in UK). They are of course clinically based, but are
nevertheless useful, and often surprisingly accurate, possibly because those GPs who subscribe to a surveillance system are
motivated to do so. GP surveillance systems are often sentinel-based, that is, based on a sample of GPs in a country, region, or
area. In the English system, GPs provide data on the base populations of their practices, so that rates of infection can be provided
as a routine, a feature that is almost unique amongst surveillance systems. Thus, they are good for common infections which to
make notifiable would possibly be wasteful, such as chickenpox. Moreover each sentinel would normally provide complete
reporting. GP surveillance systems also tend to be good for timeliness and completeness. Outbreaks of influenza are often first
recognized by GPs.

Laboratory Data
It is useful to think of laboratory data as being of qualitative rather than quantitative value as they add quality and detail to disease
surveillance. Thus, in the example already used for aseptic meningitis, a precise diagnosis of mumps, echovirus, or coxsackie type is
particularly useful in clustering and outbreaks. Indeed, as the enteroviruses exhibit a strong late summer/autumn seasonal pattern with each enterovirus returning to its baseline in winter, when numbers of a particular type continue to be reported at a level higher than the winter baseline, the return of this virus to cause another epidemic in the following summer can usually be safely predicted. Laboratory data are also essential in qualifying food poisoning and gastroenteritis. Separating viral from bacterial causes is a useful first step, as their management tends to be very different. Norovirus gastroenteritis can be food-borne, but also spreads very easily from person-to-person because an extremely small dose is necessary for infection to occur, and the virus being fairly resistant to the environment will survive for some time. Management therefore must concentrate on hygiene. Rotavirus on the other hand is not commonly known to be foodborne. It can be distinguished from norovirus by its strong winter pattern in temperate climes, and its preponderance in infants. With most bacterial causes of food poisoning, especially the salmonellas, management often depends on the removal of the offending food. This is less common with viruses – only occasionally do hepatitis A or norovirus cause outbreaks of food poisoning. Laboratory surveillance is particularly essential for unraveling the mass of respiratory viral infections that afflict humans, such as respiratory syncytial virus, adenoviruses, parainfluenza viruses, and rhinoviruses. Indeed, it is particularly useful for influenza – not only separating it from influenza-like illness, but also in identifying influenza A and B, and if A, the subtype and variant. The constituents of every influenza vaccine depend on laboratory data.

**Surveillance of Outbreaks**

Surveillance of outbreaks (as opposed to individual infections) can be revealing, and important to allow public health measures. In one incident, routine surveillance revealed two cases of hepatitis B associated with one tattooist. Inspection of the notification data on hepatitis revealed 33 cases in all associated with the tattooist. The existence of the noroviruses was suspected in the UK many years before the organisms were identified. This was because some outbreaks which did not fit the characteristics of known infections but had characteristics of their own had occurred. There are some surveillance systems specifically for outbreaks. One example is EpiWATCH. This is run by the National Health and Medical Research Council (NHMRC) Center for Research Excellence Integrated Systems for Epidemic Response in Australia. Epidemic intelligence systems such as EpiWATCH can be useful for the global surveillance of outbreaks.

**Hospital Admissions**

These can be useful for certain more serious infections, such as hepatitis and encephalitis. They can be unwieldy, generally lack detail, and often are published a year or more after the events have occurred. Special more timely surveillance systems can be created, as for example with SARS-CoV-2 in 2020.

**Serological Surveillance**

Serological surveillance has become increasingly important, and is a useful tool in assessing the immunity of a population, though it can also be used to identify vulnerable individuals. The immunity of a population can be vaccine-induced, and serological surveillance is a valuable adjunct to the methods available to monitor a mass immunization program. Vulnerable age groups can be identified, and booster doses of the vaccine introduced. An example of the importance of serological surveillance in determining public health policy is included below (analysis by person).

**Surveillance of Viruses in Nonhuman and Environmental Sources**

To build a picture of an infection, animals, birds, and the environment have been placed under surveillance. Rabies in foxes and other wildlife, influenza in birds, pigs, and other animals, are examples of important and fairly successful surveillance systems. With the more recent examples of the emerging viruses such as Nipah and the group B coronaviruses, this type of surveillance is becoming important. At the time of writing, there are some surveillance systems for influenza A virus in avians and humans. Environmental surveillance of sewage and other wastewaters for wild and vaccine polio virus, as well as other viruses, exist.

**Other Sources of Data**

Records of sickness absence, absence from school, calls to an emergency room, if available, can provide speedy information that something has happened, but tend to be nonspecific. Surveillance of antiviral resistance will become important. AIDS was first discovered in the US when the use of a drug for treatment of the then rare *Pneumocystis carinii* infection in gay men began to increase. Surveillance of prescriptions or drug usage as a means of monitoring infection will probably increase in importance.
Newer Types of Surveillance System

Syndromic Surveillance

There is no strict definition of this type of surveillance. One description is: "Syndromic surveillance complements traditional public health surveillance by collecting and analyzing health indicators in real time". It is usually based on an increase in an unusual group of clinical features which may lead to investigation. One of the earliest examples of this, though not a virological one, was the recognition of an unusual cluster of symptoms (subsequently labeled the Eosinophilia–myalgia syndrome) linked to L-tryptophan consumption originating from a single source in Japan. This was a dietary supplement manufactured using genetically-engineered bacteria. The beginning of the outbreak of SARS-CoV-2 was an increase in an association of unusual clinical features in Wuhan – in effect a new syndrome. Although there was some delay in reporting this particular unexpected increase, the primary objective of this type of surveillance is to recognize an outbreak as early as possible. Sudden changes in numbers of doctors' prescriptions for specific drugs, school or workplace absenteeism may also be used to uncover new outbreaks or new infections. Electronic surveillance systems are now being developed to detect new outbreaks – whether virological, bacteriological, or chemical. The fear of terrorism has stimulated this greater interest in syndromic surveillance. Syndromic surveillance will undoubtedly become more important with time.

Sentinel Surveillance

Sometimes, for research purposes or otherwise, more detailed or higher quality data on an infection or infections are required than normally available through a passive system. It may be too much of a burden – and probably wasteful – to expect all laboratories or other sources of data to include or collect this extra information. In this instance a form of active surveillance can be introduced. A sentinel surveillance system can be set up using a selected – and willing – number of motivated laboratories. Chosen laboratories would be expected to diagnose a reasonable number of cases of the infection, be within a fairly large area in which they would be expected to diagnose all cases of the infection, and of course to be technically excellent. Sentinel surveillance systems tend to be time limited, and are unsuitable for rare infections.

Enhanced Surveillance

Enhanced Surveillance is a term used for infections of public health importance to combine epidemiological and microbiological data, as well as other types of information necessary. It may include data from a range of sources. For COVID-19, clinical and microbiological as well as social data such as ethnic background have been collected by several countries, including from asymptomatic persons. Serological testing gives information on immunity both in a person as well as in a community. This information can be obtained from primary care and various other settings, including places of education, medical institutions and care homes. Clearly, enhanced surveillance is expensive on costs and manpower, and should only be put into practice for special reasons, such as a pandemic. Further examples covering HIV are given in the next section; many of these are also relevant to Covid19.

Active Surveillance

This is a form of enhanced surveillance to ensure completeness and consistency. Reporting sources have to report make negative returns whether or not they have had cases.

Surveillance of HIV/AIDS

The association of HIV/AIDS with stigma makes surveillance of this infection especially difficult. It is an example of the importance of tailoring surveillance to a specific serious infection if it becomes necessary to do so.

In the UK and some other countries with data protection acts, HIV infection, as with other STIs, is not notifiable. Special confidential surveillance systems through clinicians and GUM clinics, as well as laboratories, are in place. These are especially important for assessing risk factors. Inclusion of risk factors is essential for targeted intervention – for example, the proportions and rates of new diagnoses attributed to men who have sex with men, heterosexual sex, mother-to-infant, blood transfusion, IVDUs, and other needlestick injury.

Laboratory reporting is essential. Death certification is useful, though it has been shown that men who have sex with men, and probably those with other risk factors, are under-represented. In the UK, matching reported cases with death certificates is very important, as it allows for detection of deaths due to AIDS (such as pneumonia) as well as deaths associated with AIDS, and which are seen now in HIV-infected individuals – these include liver and cardiovascular disease, overdoses, and malignancies.

A surveillance system, based on unlinked anonymous testing of samples of blood taken routinely from certain at-risk population or occupational groups has been shown to provide valuable information on HIV infection in these populations. Specific screening systems for blood donors, military recruits, commercial sex workers, and family planning/termination of pregnancy

Enhanced Surveillance is a term used for infections of public health importance to combine epidemiological and microbiological data, as well as other types of information necessary. It may include data from a range of sources. For COVID-19, clinical and microbiological as well as social data such as ethnic background have been collected by several countries, including from asymptomatic persons. Serological testing gives information on immunity both in a person as well as in a community. This information can be obtained from primary care and various other settings, including places of education, medical institutions and care homes. Clearly, enhanced surveillance is expensive on costs and manpower, and should only be put into practice for special reasons, such as a pandemic. Further examples covering HIV are given in the next section; many of these are also relevant to Covid19.

Active Surveillance

This is a form of enhanced surveillance to ensure completeness and consistency. Reporting sources have to report make negative returns whether or not they have had cases.

Surveillance of HIV/AIDS

The association of HIV/AIDS with stigma makes surveillance of this infection especially difficult. It is an example of the importance of tailoring surveillance to a specific serious infection if it becomes necessary to do so.

In the UK and some other countries with data protection acts, HIV infection, as with other STIs, is not notifiable. Special confidential surveillance systems through clinicians and GUM clinics, as well as laboratories, are in place. These are especially important for assessing risk factors. Inclusion of risk factors is essential for targeted intervention – for example, the proportions and rates of new diagnoses attributed to men who have sex with men, heterosexual sex, mother-to-infant, blood transfusion, IVDUs, and other needlestick injury.

Laboratory reporting is essential. Death certification is useful, though it has been shown that men who have sex with men, and probably those with other risk factors, are under-represented. In the UK, matching reported cases with death certificates is very important, as it allows for detection of deaths due to AIDS (such as pneumonia) as well as deaths associated with AIDS, and which are seen now in HIV-infected individuals – these include liver and cardiovascular disease, overdoses, and malignancies.

A surveillance system, based on unlinked anonymous testing of samples of blood taken routinely from certain at-risk population or occupational groups has been shown to provide valuable information on HIV infection in these populations. Specific screening systems for blood donors, military recruits, commercial sex workers, and family planning/termination of pregnancy
clinics are also useful if these populations are to be targeted. Behavioral surveillance should also be seriously considered, to assist in identifying future trends, healthcare planning, as well as for specific health promotion efforts.

Attributes of Surveillance Systems

Completeness

Incompleteness is an almost universal drawback of most notification systems. They should never be dismissed for this reason alone. Statutory notification systems can be essential for surveillance and control. For common infections completeness may not be worth striving for, because notifications (assuming consistency in reporting) will generally provide information on trends, as well as fairly accurate information on age, sex and seasonal distributions, and possibly on place. Notifications were able to show a small increase in measles cases in the early 2000s which led to the need for a preschool booster.

The effect of mass vaccination programs can also be monitored fairly closely with statutory notification systems, as with measles (Fig. 1) and acute paralytic poliomyelitis (Fig. 2) in the UK. When a mass vaccination or other universal control program reduces the incidence of an infection to low levels, completeness becomes much more essential. For serious infections also, such as SARS or Lassa fever, for which contact tracing or other control measure is necessary, completeness is essential.

![Fig. 1](measles_notifications.png)  
**Fig. 1** Measles notifications: cases and deaths, England and Wales 1940–2006. Reproduced from the Health Protection Agency (www.hpa.org.uk).

![Fig. 2](polio_notifications.png)  
**Fig. 2** Notifications of acute poliomyelitis in England and Wales 1912–1993. Reproduced from the Health Protection Agency (www.hpa.org.uk).
In active surveillance, reporters make negative returns if they have had no cases during the reporting period, to ensure completeness. In some countries, enhanced surveillance has been used to assess more accurately the true incidence of an infection – regions or districts are chosen to report all cases of a particular infection or infections. It is a hybrid of active and sentinel surveillance.

**Timeliness**

Timeliness is important for infections for which urgent public health measures have to be undertaken, such as SARS-CoV-2, poliomyelitis and viral hemorrhagic fever, as well as any outbreak. In some instances, infections, not normally urgent, can become so as an elimination program progresses. In a country with elimination of measles as its goal, a case of indigenous or imported measles needs to be dealt with urgently, as it may lead to an outbreak if not controlled immediately. Laboratory data are often not timely, and hospital data generally even less so, but can make up in accuracy what they lose in timeliness.

**Accuracy**

Accuracy is clearly important, though some minor degrees of inaccuracy can be tolerated in some common infections. Clinical data are most liable to have some inaccuracies, though even laboratory data may be inaccurate. Case definitions and quality control systems can be useful to improve accuracy.

**Representativeness**

For surveillance to provide an accurate picture of the impact of a particular infection, representativeness is essential. It is perhaps the most important quality for any surveillance system. Having a wide coverage of reporting clinicians and laboratories, or a well-chosen sample of sentinel sites, is necessary for the data collected to be representative of an infection in a country. Sometimes it may be necessary to assess data from various sources, such as notifications/GPs (clinical), hospital, laboratory, and death certificates.

**Consistency**

Consistency is another crucial basic attribute of any surveillance system. Reporters must know what to report (case definition) and how often. Otherwise it will not be possible to interpret trends. Active surveillance is one way of ensuring consistency.

**Analysis of Data**

**Time**

The three basic analyzes by time, place, and person should be routine. Computer programs have made analyzes of data quicker but somewhat less flexible. There is no standard period for analysis by time. Depending on what the surveillance intends to show, yearly, quarterly, monthly, four-weekly, or weekly time intervals can be used. In surveillance, time intervals shorter than this are rarely used, although daily data were provided in many countries to monitor SARS-CoV-2. Monthly intervals have the disadvantage of having unequal numbers of days in each month, and are difficult to use when reporting is weekly; for seasonal trends four-weekly periods are better but cannot be divided into quarterly periods. In viral surveillance, four-weekly rather than weekly intervals tend to be most useful in showing seasonal changes. There is more likely to be more variation ("noise") in weekly intervals, making for less smooth changes. For secular trends, quarterly or annual intervals are generally used. Analyzing by time can reveal regular changes in the periodicity of viruses, enabling some of them to be predicted.

A basic knowledge of seasonal and secular patterns makes it easier to detect changes that signify a possible epidemic, and to differentiate these from a random variation. It is important to remember when analyzing laboratory data that there is often an interval, which can be 2 weeks or more, between date of onset and date of reporting.

**Person**

Analysis by age and sex is another basic analysis in surveillance. It can identify those most affected, and vulnerable groups. Changes in age distributions may provide important clues about a changing viral infection, and the effect of mass interventions on the age distribution of an infection can be monitored. Changes in the age distribution of measles in 1994 in the UK signified that an epidemic in older children was imminent, and the vaccine schedule was changed to include an extra booster injection (MR) to children aged 5–16 years. This averted the outbreak and the booster dose became a permanent feature of the routine immunization schedule in the UK. Indeed the changes in age distribution following mass vaccination could be considered an epidemiological side effect of mass vaccination. Requests for occupational groups and travel histories should be selective. For poliomyelitis, SARS, dengue, and the viral hemorrhagic fevers, travel histories are required. Occupational group may be useful for norovirus, and hepatitis types A, B, or C. Specific risk factors may be worthwhile for HIV, hepatitis B and C.
Place

Analysis by place can pinpoint local outbreaks. Some echoviruses (e.g., echovirus type 4) can cause rare short local outbreaks, other types (e.g., types 9 and 11) are more common and more widespread. Food-borne outbreaks of hepatitis A and norovirus are generally picked up locally through routine surveillance, but sometimes more extensive outbreaks caused by a more widely distributed foodstuff, including shellfish or frozen soft fruit, may be identified.

Interpretation

Collection and analysis are generally routine functions; skill is required in interpretation of the data. No statistic is perfect, and surveillance data, like all data, must be interpreted with caution. One must take into account the origins of the data – clinical, laboratory, or hospital. Not only must the reliability, or otherwise, of the data be evaluated, but what the data signify in the natural history of the infection must also be recognized.

Every viral infection has its stages and these must be recognized before surveillance data can be sensibly interpreted. At what stage are the data being collected important to understanding and interpretation? Using influenza or hepatitis A as examples, and a defined population (Table 1), only a proportion of persons in the defined population will be infected with the virus. They can only be comprehensively detected by screening, and serological surveillance will identify these persons, or assess population immunity (B1 in Table 1). In HIV/AIDS surveillance, unlinked anonymous testing of samples of blood taken routinely at say, an antenatal clinic, can give vital information on the prevalence of HIV infection, since in this infection presence of antibody denotes infection, not immunity. A smaller proportion will be ill (B2), but only some of these will visit a doctor (B3). Surveillance systems based on GP consultation rates have now been recognized as an important addition to the spectrum of a disease, and many countries have excellent systems. Of those patients that do visit their family doctor, only some will be admitted to hospital (B4). Finally, only some will die (B5).

For laboratory data, the stages are slightly different (Table 2), but still important in understanding what the reported data mean. As before, only a proportion of persons will be infected (B), some will be asymptomatic (B1), a smaller proportion will be ill (B2), and an even smaller proportion still visit their doctors (B3). Not all doctors will send specimens to a laboratory (B4), and only a proportion of these specimens (B5), depending on accuracy of the identification process, the method of transport, the fragility of the organism, and the swabbing or other sampling technique, will be positive. Finally, depending on the level of consistency of reporting, only some of these will be reported (B6). It is essential to recognize these stages in interpreting surveillance data.

Biases will inevitably occur between these stages. Collection of data in routine surveillance is not normally a scientific process as one has to rely on readily available data – data obtained mostly for other reasons, such as to make a definitive diagnosis. Only the most severe cases die, and death certification thus provides, at best, a limited view of any disease. Similarly, only certain types and severity of cases will be admitted to hospital (some admissions are for social reasons for example) or even visit their family doctor.

| Table 1 | Stages of a viral infection |
|---------|-----------------------------|
| **Clinical** |                           |
| A. Uninfected |                           |
| B. Infected |                           |
| 1. Asymptomatic |                           |
| 2. Symptomatic unreported |                           |
| 3. Symptomatic, sees a doctor |                           |
| 4. Symptomatic, admitted to hospital |                           |
| 5. Symptomatic, dies/survives |                           |

*Note: Chronic carriers can occur at any of the B stages – for example, hepatitis B or C.*

| Table 2 | Stages in laboratory diagnosis |
|---------|--------------------------------|
| A. Uninfected |                           |
| B. Infected |                           |
| 1. Asymptomatic |                           |
| 2. Symptomatic, unreported |                           |
| 3. Symptomatic, sees a doctor |                           |
| 4. Symptomatic, specimens submitted |                           |
| 5. Symptomatic, specimens positive |                           |
| 6. Symptomatic, specimens reported to surveillance system |                           |
Certain age, sex, and perhaps social or occupational groups are more likely to seek medical help, be investigated and be reported. In laboratory data, more severe cases, or children, are perhaps much more likely to be investigated in detail. These shortcomings of surveillance data do not make them useless – but their strengths and limitations must be recognized.

**Feedback**

If interpretation is turning statistics into information, feedback is getting the information across to those that matter, and those that need to know, so that action – the objective of surveillance – can be taken. Without feedback, surveillance is pointless. Feedback is most likely to be informative if undertaken by those most closely involved in the surveillance cycle, and who understand the significance of the data they are receiving.

Feedback should be aimed at contributors and those in public health. Contributors will then be aware of which viruses are circulating and this will help them to know what to look for in their own tests (e.g., what echovirus or adenovirus types are in circulation). Moreover, routine surveillance will undoubtedly uncover outbreaks of infection, which will need further investigation and control at local, national, and even international level. An interesting and welcome side effect of a flourishing microbiological/feedback surveillance system is that it often stimulates better quality control within reporting laboratories.

Regular feedback is essential, not only to contributors, but also to those who can act for the public health. Regular and useful feedback encourages good and regular reporting. Generally, the periodicity of feedback should reflect the frequency of reporting – weekly feedback for weekly reports for example. Regular topic-based reviews are also important.

**Evaluation of Surveillance**

A surveillance system is like a country’s train system. Once the rail lines have been built, the goods that will be carried along those lines can be changed according to need. Similarly, in a surveillance network, once the lines of communication have been laid down, the data being reported can be changed according to what is most important at the time (though probably not too frequently). Nevertheless, surveillance systems should ideally be frequently evaluated for usefulness, as well as for accuracy, efficiency, and effectiveness.

They should also be sufficiently flexible, so that “new” or emerging infections can be included in an emergency or when the need arises. The successful implementation of international surveillance for SARS was instrumental in controlling it. Emergency surveillance was also essential following the tsunami of 2004, and is also necessary for the successful management of other disasters following earthquakes, hurricanes, and floods.

Surveillance systems should be evaluated before they are set up, and again at regular intervals thereafter. Before implementing a surveillance system, is there an adequate public health and administrative infrastructure in place to take action? Are the data to be collected representative and sufficiently timely for the specific infection? Are they useful, and is action being taken on the information? If not, is the feedback inadequate?

**Global and International Surveillance**

The ease and speed of modern travel, the distribution of goods (especially foodstuffs) across increasingly wide parts of the world, and the uncontrollable spread of birds and other wildlife across boundaries has made global and international surveillance essential for outbreak and infection control. Surveillance of viral infections such as influenza and SARS-CoV-2 now requires the expertise of many professionals – epidemiologists, virologists, and vaccinologists, clinicians, statistical modelers, veterinarians, managers, and planners. These occur in many different countries so that information can be exchanged, and attempts made on a global basis, to prevent the next pandemic. Epidemics of ZIka virus, dengue and West Nile virus have also spread widely recently. AIDS/HIV was destined to become a global problem almost from the time of its first discovery. On a more positive note, SARS was contained through the use of international surveillance; and surveillance was the backbone of the smallpox eradication program.

International surveillance can also be used for the detection of international outbreaks of food poisoning caused by the distribution of foodstuffs across a wide number of countries. An outbreak of hepatitis A in England was caused by frozen raspberries grown and frozen in another country; and another outbreak of hepatitis A, this time in Czechoslovakia (before it became separate republics) was caused by strawberries used to make ice cream; the strawberries had been imported from another Eastern European country. There are now well-established trans-European surveillance systems for salmonella infections and legionnaires’ disease, as well as for viral infections.

The need for surveillance will never diminish or disappear. Surveillance systems will only improve, become increasingly sophisticated, and become increasingly relied upon and used. Control of infection will not be possible without it.
Further Reading

Charrel, R.M., de Lamballerie, X., Raoult, D., 2007. Chikungunya outbreaks – The globalization of vectorborne diseases. New England Journal of Medicine 356, 769–771.

Chin, J. (Ed.), 2002. Control of Communicable Diseases Manual, seventeenth ed. Washington, DC: APHA.

Chorba, T.L., 2001. Chapter 7 – Disease surveillance. In: Thomas, J.C., Weber, D.J. (Eds.), Epidemiologic Methods for the Study of Infectious Diseases. Oxford: Oxford University Press.

Colon-Gonzalez, F.J., Lake, I.R., Morbey, R.A., et al., 2018. A methodological framework for the evaluation of syndromic surveillance systems: A case study of England. BMC Public Health 18, 544. doi:10.1186/s12889-018-5422-9.

Communicable Disease Report, 1994. National measles and rubella immunisation campaign. Communicable Disease Report Weekly 4 (31), 146–150.

Heymann, D., Rodier, G.R., 1998. Global surveillance of communicable diseases. Emerging Infectious Diseases 4, 362–365.

McCormick, A., 1989. Estimating the size of the HIV epidemic by using mortality data. accessed date: 05.08.89. doi:10.1098/rstb.1989.0081.

Noah, N., 1989. Cyclical patterns and predictability in infection. Epidemiology & Infection 102 (2).

Noah, N., 2006. Controlling Communicable Disease. Maidenhead, UK: Open University Press, pp. 14–19. (chs. 1–4).

UNAIDS, 2003. Introduction to second generation HIV surveillance. Available at: http://www.data.unaids.org/Publications/IRC-pub03/2nd_generation_en.ppt (accessed September 2007).

Thomas, M.E.M., Noah, N.D., Tillett, H.E., 1974. Recurrent gastroenteritis in a preparatory school caused by Shigella sonnei and another agent. Lancet 1, 978–981.

Relevant Websites

http://www.cdc.gov
Centers for Disease Control and Prevention (CDC).

http://www.eiss.org
EIS Scotland’s Largest Teaching Union.

http://www.eurosurveillance.org.
Eurosurveillance.

https://iser.med.unsw.edu.au/epi-watch-outbreak-alerts
NHMRC Centre for Research ExcellenceIntegrated Systems for Epidemic Response.

http://www.hpa.org.uk
Public Health England - GOV.UK.

http://www.EWGLI.org
Service unavailable.

https://www.thedailybeast.com/were-fighting-polio-with-sewage-surveillance
We’re Fighting Polio With Sewage Surveillance.

http://www.who.int
World Health Organization: WHO.