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Information and communication technologies for disease surveillance: a review of architectures, data sources, and applications

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ABSTRACT

Information and communication technologies (ICTs) have significantly expanded the capabilities of disease surveillance by enabling faster data collection, integration, analysis, and dissemination. This review examines the role of ICTs in disease surveillance, focusing on system architectures, conventional and emerging data sources, and public health applications. It discusses electronic reporting systems, syndromic surveillance, health information networks, mobile technologies, geographic information systems, and Internet-based biosurveillance. These technologies provide opportunities to improve outbreak detection, monitor disease trends, and support coordination among healthcare providers and public health authorities. However, their effectiveness depends on data quality, interoperability, timeliness, representativeness, and the capacity to translate digital signals into appropriate public health responses. Particular attention is given to the limitations of nontraditional data sources, including online news, web searches, and user-generated information, which may introduce bias and false signals. The review highlights the need for integrated surveillance architectures that combine multiple data sources with epidemiological validation and sustainable institutional arrangements. Finally, research directions are identified to strengthen the reliability, scalability, and practical value of ICT-enabled disease surveillance systems.

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1. INTRODUCTION

Disease surveillance is a fundamental public health activity for detecting health threats, monitoring disease trends, and guiding prevention and control measures. Traditionally, surveillance has relied on routine case reporting, laboratory notifications, disease registries, and epidemiological investigations. However, these approaches may experience reporting delays, fragmented information, and limited capacity to detect emerging events rapidly.

Information and communication technologies (ICTs) have created new opportunities to improve the collection, exchange, and analysis of surveillance information. Electronic health records, laboratory information systems, mobile devices, geographic information systems, and Internet-based platforms can provide complementary sources of information for monitoring disease occurrence. Choi [1] emphasized that advances in computing and communication technologies can strengthen surveillance by improving data collection, analysis, dissemination, and global coordination.

Nevertheless, technological capability alone does not guarantee effective disease surveillance. Digital systems must produce information that is sufficiently accurate, timely, representative, and actionable for public health decisions. This review examines ICT-based surveillance architectures, data sources, applications, and implementation challenges, emphasizing the need to connect technological innovation with epidemiological practice.

2. ICT-BASED DISEASE SURVEILLANCE ARCHITECTURES

An ICT-based disease surveillance system is an interconnected infrastructure for acquiring, processing, storing, analyzing, and disseminating health-related information. Its architecture typically includes data providers, communication interfaces, data integration services, storage repositories, analytical components, and reporting or visualization tools. The architecture must support reliable information exchange while accommodating different data formats, organizational requirements, and surveillance objectives.

Lober *et al.* [2] described essential architectural components for syndromic surveillance, including data acquisition, vocabulary standards, data transport, security, transformation, normalization, and analytical repositories. Their work demonstrated that surveillance architecture should be designed as an integrated information system rather than as an isolated reporting application. The separation of data acquisition, processing, and analysis also supports system flexibility when additional data providers or surveillance functions are introduced.

A centralized architecture collects information from multiple sources into a common repository for processing and analysis. This approach can simplify data management and provide a unified view of surveillance indicators, although it may create dependencies on central infrastructure and data transmission. A distributed architecture allows participating organizations to retain greater control over their information while exchanging selected data or analytical results, but it requires consistent interoperability mechanisms and coordination.

The choice of architecture should reflect the surveillance context and operational requirements. Systems designed for national disease reporting may prioritize standardization and centralized coordination, whereas local outbreak monitoring may require flexible integration and rapid communication. German *et al.* [3] emphasized that surveillance systems should be evaluated according to attributes such as simplicity, flexibility, data quality, acceptability, sensitivity, representativeness, timeliness, and stability.

3. DATA SOURCES AND ICT TECHNOLOGIES

The effectiveness of disease surveillance depends on the diversity, quality, and suitability of its data sources. Conventional sources include clinical reports, laboratory results, hospital records, disease registries, and emergency department information. ICT enables these sources to be collected and exchanged more efficiently, reducing dependence on manual reporting and supporting more frequent updates.

Electronic health records and laboratory information systems provide important clinical data for disease monitoring. Electronic laboratory reporting can accelerate the transmission of diagnostic results to public health authorities, while clinical records can provide additional information about symptoms, diagnoses, and patient characteristics. Johnson *et al.* [4] discussed recommendations for using inpatient and ambulatory EHR data in syndromic surveillance, highlighting the importance of selecting appropriate data elements and defining consistent reporting procedures.

Syndromic surveillance uses symptoms, clinical complaints, and other early indicators to identify unusual patterns before laboratory confirmation is available. Emergency department visits, outpatient consultations, ambulance records, and telephone health-service data can provide timely indicators of changes in disease activity. Ziemann *et al.* [5] found that the usefulness of syndromic data sources depends on their timeliness, validity, data quality, and surveillance purpose, with healthcare service data often providing greater specificity than some alternative sources.

Mobile technologies offer additional opportunities for collecting and transmitting surveillance information, particularly where conventional reporting infrastructure is limited. Mobile phones can support field reporting, case investigation, health worker communication, and the transmission of geographic information. Their practical value, however, depends on network availability, device access, user training, data security, and the reliability of information entered by field personnel.

Internet-based sources have also expanded the scope of disease surveillance. Online news, official announcements, expert reporting networks, web searches, and user-generated content can provide early indications of unusual health events. Brownstein *et al.* [6] described how Internet information can complement traditional surveillance by providing alternative views of disease activity, while Freifeld *et al.* [7] demonstrated automated collection, classification, integration, and visualization of outbreak reports through the HealthMap platform.

4. DATA INTEGRATION AND INFORMATION PROCESSING

Data integration is essential because disease-related information is distributed across independent organizations and technological platforms. Healthcare providers, laboratories, public health agencies, and digital information services may use different data structures, terminologies, and communication protocols.

ICT-based surveillance must therefore provide mechanisms for combining information while preserving its meaning, source, and temporal context.

The integration process commonly involves data acquisition, validation, standardization, transformation, storage, and analysis. Data cleaning is necessary to identify incomplete records, duplicated reports, inconsistent disease names, and inaccurate geographic information. Automated text processing can also classify unstructured reports according to disease, location, and event characteristics, as demonstrated by the HealthMap architecture [7].

Interoperability requires both technical compatibility and semantic consistency. Standardized message formats and exchange protocols allow systems to transfer information, while shared terminologies and coding systems help ensure that exchanged data are interpreted consistently. Without these capabilities, the integration of multiple sources may increase data volume without necessarily improving the reliability of surveillance outputs.

5. APPLICATIONS IN DISEASE SURVEILLANCE

ICT-based surveillance supports several public health applications, including outbreak detection, disease trend monitoring, situational awareness, and emergency response coordination. Automated reporting can improve the availability of laboratory and clinical information, while syndromic systems can identify unusual patterns that require further investigation. Choi [1] emphasized that surveillance information becomes valuable when it supports planning, implementation, and evaluation of public health action.

Internet biosurveillance provides a complementary approach by monitoring information from online sources. Barboza *et al.* [8] reviewed Internet biosurveillance as a means of identifying emerging health threats through unstructured digital information. Such systems can provide early warnings and situational awareness, particularly when official reporting channels are delayed or incomplete, but their signals require verification through epidemiological investigation.

HealthMap illustrates how ICT can transform diverse online reports into geographically organized surveillance information. The system combines news media, expert-curated reports, and official alerts, then applies automated text processing to classify disease events and locations [7]. Its evaluation demonstrated the practical value of automated information processing, while also showing that source characteristics influence classification accuracy and the need for human review.

Syndromic surveillance has also evolved from early warning toward broader situational awareness and response. Josseran and Fouillet [9] discussed this evolution and emphasized that surveillance should connect signal detection with the actions required to manage public health events. This perspective highlights an important principle: a surveillance system should not be judged solely by its ability to generate alerts, but also by its contribution to effective public health responses.

6. CHALLENGES AND LIMITATIONS

Data quality and representativeness remain major challenges for ICT-based disease surveillance. Clinical reporting systems may contain missing information, inconsistent coding, delayed updates, or duplicate records, while online sources may include rumors, unverified reports, and geographically ambiguous information. These limitations can produce misleading trends and reduce confidence in surveillance findings.

Timeliness must also be balanced against validity and specificity. Nontraditional digital sources may identify potential events earlier than conventional reporting systems, but early signals may generate false alerts or reflect public attention rather than actual disease occurrence. Ziemann *et al.* [5] showed that data sources differ in their usefulness according to surveillance objectives and context, supporting the need for source-specific evaluation.

Interoperability and system sustainability create further implementation difficulties. Different organizations may use incompatible information systems, lack standardized reporting procedures, or have limited resources for maintaining digital infrastructure. These constraints are particularly important in settings where public health agencies depend on external healthcare providers for timely and complete information.

Privacy, security, and ethical governance must also be addressed when surveillance systems collect and exchange personal health information. Appropriate access controls, secure communication, data minimization, and clear rules for information use are necessary to protect individuals and maintain public trust. The use of publicly available digital information also requires careful consideration of accuracy, privacy expectations, and the potential consequences of misinterpretation.

7. COMPARATIVE ANALYSIS AND RESEARCH DIRECTIONS

ICT-based surveillance approaches provide complementary capabilities rather than interchangeable solutions. Conventional clinical and laboratory sources generally offer greater diagnostic relevance, while syndromic and Internet-based sources may provide earlier signals of potential health events. Table 1 summarizes their principal characteristics and limitations.

Table 1. Comparative analysis of ICT-based disease surveillance data sources

Data source or technology	Main contribution	Major strength	Main limitation
Electronic health records	Clinical and symptom monitoring	Detailed patient-level information	Incomplete coverage and inconsistent documentation
Laboratory reporting systems	Diagnostic confirmation	High clinical specificity	Reporting and processing delays
Syndromic surveillance	Early detection of unusual patterns	Timely indicators before confirmation	False alerts and limited specificity
Mobile technologies	Field reporting and communication	Flexible data collection and rapid transmission	Network, access, and data quality constraints
Internet and online media	Event-based surveillance	Broad and rapid information access	Unverified information and reporting bias
Geographic information systems	Spatial analysis and visualization	Identification of geographic patterns	Dependence on accurate location data

Future research should focus on integrated surveillance architectures that combine conventional and nontraditional information sources. Such systems should preserve source provenance, support standardized data exchange, and apply validation procedures before generating public health alerts. The integration of multiple sources should improve situational awareness without treating every digital signal as confirmed epidemiological evidence.

Another important direction is the development of evaluation frameworks that assess both technical performance and public health value. Evaluation should consider data quality, detection timeliness, sensitivity, specificity, representativeness, system stability, and the usefulness of alerts for decision-making. These criteria can help determine whether new ICT applications provide meaningful improvements over established surveillance practices.

Research should also address the sustainability of ICT-based surveillance in resource-constrained settings. Mobile reporting, open-source platforms, and distributed architectures may offer practical alternatives where centralized infrastructure is difficult to maintain. However, technological solutions must be accompanied by workforce development, institutional coordination, secure data governance, and long-term operational support.

8. CONCLUSION

ICTs have expanded disease surveillance through improved data acquisition, integration, analysis, and dissemination. Electronic health records, laboratory systems, mobile technologies, syndromic surveillance, geographic information systems, and Internet-based platforms provide complementary information for monitoring disease patterns and detecting potential public health threats. Their effectiveness, however, depends on data quality, interoperability, representativeness, security, and the capacity to translate information into appropriate public health action. The review indicates that ICT-based disease surveillance should be developed as an integrated technological and organizational capability. Combining multiple data sources can improve timeliness and situational awareness, but digital signals must be validated and interpreted within an epidemiological context. Future research should emphasize interoperable architectures, reliable data integration, systematic system evaluation, and sustainable implementation to strengthen the contribution of ICT to disease prevention and control.

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