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Population Health Technologies

Emerging Innovations for the Health of the Public

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Abstract: At the beginning of the 21st century, we are at the dawn of a possibly unprecedented era of scientific discovery and promise. Emerging technologies, including information and communication technologies, genomics, microelectromechanical systems, robotics, sensors, and nanotechnologies, provide enormous opportunities for population health improvement. Population health technology refers to the application of an emerging technology to improve the health of populations. Emerging technologies present an opportunity for addressing global health challenges—in both developed and developing countries. Health issues ripe for the application of new technologies include disease surveillance and control, environmental monitoring and pollution prevention, food safety, health behavior change, self-care, population screening, and chronic disease and injury prevention and control. If appropriately applied, population health technologies may greatly enhance existing health intervention models. However, potential adverse consequences could arise related to privacy, confidentiality, and security; quality and effectiveness; sustainability; and the technology divide. To ensure the optimal development and diffusion of population health technologies will require balancing these risks and benefits while simultaneously adopting new mechanisms of public and private support for research and development in this potentially important new domain of public health.
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Introduction

Technology innovation is a major driver of the global economy, quality of life, and health improvement. In the previous century, many technologic advances have contributed substantially to the health of individuals and communities. For example, childhood immunizations have reduced prevaccine morbidity from nine vaccine-preventable diseases in the United States by an average of 99% between 1900 and 1998, and they have virtually eliminated previously common diseases, such as diphtheria, tetanus, poliomyelitis, and smallpox.[1,2] The incidence of many foodborne diseases, including typhoid fever, tuberculosis, and botulism, have dramatically declined primarily as a result of health-related innovations, such as pasteurization, sanitation, and home refrigeration.[3] Diseases caused by nutritional deficiencies have been virtually eliminated in many developed countries through the use of food fortification. In addition, advances in vehicle and highway design, such as energy-absorbing steering wheels, safety belts, and highway barriers, helped reduce the U.S. death rate per vehicle miles traveled by more than threefold from 1966 to 1999.[4,5]

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At the beginning of the 21st century, we are at the dawn of a possibly unprecedented era of scientific discovery and promise. Emerging information and communication technologies, genomics, microelectromechanical systems, robotics, sensors, and nanotechnologies are some of the many emerging technologies that provide new opportunities for population health improvement.[6,7] Further exploration of how such technologies can contribute to population health purposes is needed.

Many population health organizations do not yet use technology innovations. The entire *Encyclopaedia Britannica* can be transmitted over the Internet across the United States in less than 1 second, but it could take weeks to months before a reportable disease is communicated to public health officials (estimated transmission time based on size of the *Encyclopaedia Britannica* being about 1 gigabyte and transmission over a 10 gigabit/second Internet2 network, such as Abilene). At a time when prototype nanotechnologies can detect the presence of diagnostic proteins and genetic material in molecular-scale quantities, most countries continue to rely on an antiquated system of crude organoleptic inspections to ensure the safety of our food supply.[8,9] As SARS (severe acute respiratory syndrome) and other recent disease outbreaks illustrate, current global disease surveillance systems and the public health infrastructure are grossly inadequate in monitoring and containing public health threats.[10] In fact, technologies

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Table 1. Sample definitions of major terms used

Term	Sample definitions[a]
Consumer health informatics	"The use of modern computers and telecommunications to support consumers in obtaining information, analyzing their unique health care needs, and helping them make decisions about their own health."[15]
eHealth	"The use of emerging information and communication technology, especially the Internet, to improve or enable health and health care."[14]
Emerging technologies	Technologies that are expected to have substantial impact within 5–10 years but are not yet commercialized or widely adopted.
Population health	"The health of a population as measured by health status indicators and as influenced by social, economic and physical environments, personal health practices, individual capacity and coping skills, human biology, early child development and health services."[16]
Population health technology	The application of an emerging technology to improve the health of populations.
Public health informatics	"The systematic application of information and computer science and technology to public health practice, research, and learning."[17]

[a]Many definitions exist for these terms; these do not necessarily represent consensus of professionals in the field.

used by the U.S. trucking industry to monitor vehicles, optimize routing, and communicate with drivers are much more advanced than that used by public health professionals to track health problems, optimize services, and communicate.[11,12]

How Technology Can Improve Population Health

Population health focuses on the multiple factors—biological, behavioral, environmental, and social—that influence the health of groups of people.[13] A population health approach develops and implements interventions to improve the health of the entire population, not just individuals. Such interventions can be environmental, educational, organizational, social, or technologic in nature. Population health technology (PHT) is defined as the application of an emerging technology to improve the health of populations. Clearly, this definition could overlap with other concepts, but, for the purposes of this paper, public health is considered a subset of population health, and PHT as a subset of eHealth technologies.[14] Population health technology focuses on technologies that improve health on a population level rather than in an individually focused, medical care context. Thus, PHTs typically emphasize preventive, behavioral, environmental, social, and systems-oriented interventions rather than medically oriented ones. Although related terms, such as "consumer health informatics" and "public health informatics" might encompass some aspects of PHT, these terms focus primarily on information technology (IT) and, in many cases, solely on software applications (Table 1).[15–17] Population health technology is proposed as a broader concept that includes non–IT-emerging technologies. This paper highlights the opportunities and challenges posed by PHTs, and it describes a path to promote and accelerate their development and diffusion.

Population health issues ripe for the application of innovative technologies include disease surveillance and control, environmental monitoring and pollution prevention, food safety, health behavior change, self-care, population screening, and chronic disease and injury prevention and control. Examples of possible PHT products include middleware (software) that allows the seamless integration and analysis of health-related databases; real-time, virtual, individually tailored health advisors that can provide answers to any health question at anytime; sensors that can detect the presence of alcohol or drugs in a driver's body and prevent the operation of the vehicle; remote-sensing technologies that monitor environmental conditions related to disease occurrence and community decay; clean energy technologies that reduce environmental emissions and related health effects; and "smart" houses with networked, intelligent appliances that promote health.

An example of how a specific PHT could improve population health follows. Several companies have developed networked sensors that can detect acoustic signatures of gunshots.[18] Mounted on rooftops or other structures, not only can these sensors distinguish a gunshot from ambient noise (e.g., backfire from car), but they can also discern the make of the firearm. Networked together, they can triangulate the position of the firearm and the trajectory of the bullets. Within seconds, they can send emergency alerts to police and emergency services and to local residents. This type of technology could help prevent gun-related violence in distressed neighborhoods, and it also could provide essential data about the gunshot incidence that can be used by local residents to advocate for improved public safety programs and additional resources. In the near future, such networked sensor technology need not be limited to the monitoring of gunshots, fires, air pollution, or other events that might be obvious or abrupt in nature. For example, future sensor technologies could be able to detect subtle deterioration of neighborhood infrastructure, such as damage to streets, sidewalks, parks and trees, and neglected buildings. They could

also be used to anonymously monitor the relationship between such degraded neighborhoods and physical activity levels of local residents or visitors. Such technologies would help fill a void in our ability to identify and remedy local health problems before entire communities deteriorate. Of course, as with some other PHTs, many concerns, including privacy and appropriate use, need to be carefully evaluated before deployment. Appropriate roles for public health professionals in the context of these emerging technologies include helping consumers elucidate their needs and priorities, translating those needs to technology developers, working with developers to pilot PHTs, evaluating the effectiveness of the technology, and engaging in policymaking processes about appropriate funding and uses of PHTs.

Some technologies have already demonstrated their utility for population health. For example, geographic information systems (GIS), which integrate, analyze, and visualize data related to physical location and time, have been successfully applied in a range of population health issues, including disease surveillance and emergency planning and management, monitoring of crime and at-risk neighborhoods, and tracking environmental exposures.[19] Benefits include increased ability to link exposures to outcomes, improved program decision making and planning, and greater support for community advocacy.

If appropriately applied, PHT could fundamentally change many existing health intervention models and paradigms. With new PHTs, it could be possible to detect disease outbreaks early enough to prevent primary and secondary transmission, empower people to make the best health decisions at the exact time of decision-making, enable communities to monitor and address local health and environmental issues before they become significant hazards, and cost-effectively screen entire at-risk populations for dozens of diseases with a single drop of blood or saliva. It might not be self-evident that some health technologies targeted for and deployed by individuals or patients can be considered "population" health technologies when adopted throughout a community. For example, technologies that support chronic disease management outside health care settings could prevent complications from these conditions, which is an important population health concern.

To date, few investors and technology developers have paid attention to population health–oriented products compared with individually oriented, medical care interventions (e.g., diagnostics and treatment modalities). This emphasis is reflected in the fact that the bulk of the health care expenditures in the United States—$1.3 trillion in 2000—is spent on medical care interventions.[20] Although no official data are collected on PHT expenditures, such investment is likely insignificant compared with support for medical technology research and development (R&D). For example, pharmaceutical companies belonging to a major industry trade group invested more than $30 billion in R&D in 2001[21]; this investment does not include expenditures by other medical care industries, such as device and equipment manufacturers. There is no major public or private funding program for PHT R&D to my knowledge.

In addition, the markets for PHTs have not been well defined, and there is a lack of professional and public understanding of this nascent field. Whereas there is a strong track record of technology transfer among disciplines like computer science, commercialization of ideas from population health–related institutions, such as schools of public health, is rare because they lack the technology or business expertise to develop or commercialize technologies. Similarly, technologists and entrepreneurs typically do not have the necessary expertise in population health and research. Development of PHTs requires a multidisciplinary and multisector approach that involves stakeholders who do not usually communicate or collaborate with each other. Unfortunately, there is a lack of national and global leadership and supporting infrastructure to address the above deficits.

Rate-Limiting Factors

Population health technologies could dramatically improve our ability to detect, monitor, and address population health problems, but, when used inappropriately, they also could have substantial deleterious effects. A systematic and deliberate approach to PHT development and dissemination is warranted to ensure that these innovations do not result in harm or waste limited resources. Four general areas merit careful consideration as we move forward.

Privacy, Confidentiality, and Security

Adoption of some PHTs will partly depend on the extent that public concerns about privacy, confidentiality, and security of online data are addressed.[22] A huge volume of data will be generated by the use of future PHTs either intentionally by users or automatically by networked devices, such as information appliances and sensors. Product developers and policymakers will need to proactively balance public concerns about privacy protections with the information-sharing needs of some business models and public health programs. Policies, regulatory and otherwise, will need to keep pace with technologic innovation. For example, the rules recently promulgated under the Health Insurance Portability and Accountability Act (HIPAA) fail to address the substantial volume of data generated by most eHealth applications.[23] Failing a comprehensive approach, the impending proliferation of sensitive health data—and associated potential abuses—might

dwarf many benefits of PHT. In addition to appropriate policies, more work is needed on methods for data collection and management to ensure that such data are used in the best interests of individuals and public health. For example, model "data contracts" could be developed to ensure that individuals—perceived by many to be the real "owners" of most health data—have control over and receive direct benefit from the use of their data.

Quality and Effectiveness

As novel PHTs emerge, funders, purchasers, and users should consider their evidence base before they are widely implemented.[24,25] Many PHTs will not only be complex products themselves, but they will also be networked to, and sometimes operate synergistically with, other equally sophisticated applications. In these instances, the potential for unintended errors is magnified. Minimizing this risk can be achieved by integrating quality improvement and evaluation processes throughout the product development life cycle.[26] Existing approaches and tools for quality assurance of health websites could be applied to PHTs, but more robust and dynamic mechanisms also are needed.[27,28]

Research and evaluation tools for PHTs will likely be refined in the context of real-life trials. Given that many PHTs have origins in disparate scientific disciplines, research and evaluation of these technologies likely will require research teams across multiple fields. In addition, emerging technologies will stretch the limits of existing research methods that historically have been applied to more static and less robust interventions.[29] The ultimate question to be considered is "What is the health and social impact of the intervention on the population level?" The challenge will be to develop consensus methods and metrics around this fundamental question.

Because PHT products have not been widely deployed, rigorous outcome studies are limited. Thus, some readers might believe that it is premature to promote PHTs, given the lack of empirical evidence for some PHTs. However, it should be noted that many traditional (non-technology-based) population health interventions, which have been in practice for decades, do not have empirical evidence of benefit.[30]

Sustainability

Population health technologies can be financed and sustained through two major ways: (1) commercial ventures and sales or (2) government and foundation support. For many PHTs, commercial viability is a prerequisite for widespread adoption. Is or will there be sufficient market demand for these technologies? Because of the diversity of potential PHTs, it is impossible to answer this question outside the context of a specific product. However, consider the history of automobile safety technologies. When seat belts and airbags were first introduced in the United States, the automobile industry strongly opposed them because they believed that consumers would not be willing to pay the added costs.[31] But car manufacturers now routinely highlight safety features as a major marketing strategy.[32] Market demand for automobile safety technology has evolved to the point where it would be difficult to sell a car without these features even if they were not legislated.

Because public health agencies—the traditional funders of most population health programs—might lack adequate budgets to support PHT deployment, new business models are needed to sustain PHTs. The appropriate business model is product specific, but possible sources of support include both end users and health intermediaries, such as corporations, employers, health care providers, and health plans.

Market demand for many PHTs likely will crystallize when the benefits of such technologies become clear to potential users. In cases in which the commercial viability of a specific PHT is marginal or unclear, government agencies and foundations could fund those technologies that serve the public interest or subsidize their use among certain populations. Regardless of the source of funding, a compelling return on investment is necessary for health technology investment and adoption.[33] In the case of PHT, a social return on investment analysis, which attempts to quantify and monetize social return, also could be a useful assessment model for funders.[34]

Technology Divide

Concerns about a widening technology divide will be heightened when PHTs become widely available for consumers. Addressing the multidimensional nature of technology access, including physical access to infrastructure and equipment, availability of relevant applications, health and technology literacy, and usability, must be a priority to ensure that PHTs will be accessible to all.[35] At the same time, progress in developing PHTs should not be held back in fear that such a divide will grow. Technology innovations typically diffuse from "early adopters" and others before they are widely adopted in the population.[36] The diffusion process could help refine the technology and sustainable business models.[37] Looking back, the personal computer was largely irrelevant and unaffordable to the general U.S. population in the 1980s. But with affordable prices and the added value proposition of Internet access in the mid-1990s, demand for personal computers skyrocketed. Few people would argue now that development of innovative Internet applications should have been held back because of concerns about the digital divide.

PHT presents a compelling opportunity for addressing global health challenges, from underserved groups

in the developed world to those in less-developed countries.[38] Developing economies may be ideal sites for PHTs precisely because they currently lack technology infrastructure—a situation that encourages the deployment of "leap-frog" technologies. For example, in some developing areas, wireless phones have been adopted rapidly in areas without land-line connections, and wireless phones now outnumber land-line phones. In addition, less-developed countries that have a dire need for high-impact interventions because they have limited health care and public health options are usually very receptive to new technologies and typically have fewer status quo institutions and policies that might hinder the deployment of new technologies.

Catalyzing Development and Diffusion of PHT

The following activities should be considered in building the field of PHTs and in accelerating their development and diffusion.

Infrastructure Development

National and global infrastructures are needed to support PHT development and dissemination. Appropriate infrastructure could help set national and global agendas for development of high priority PHTs, provide technical and business assistance to developers, optimize available resources by creating networks of individuals with related interests and skills, develop common tools and materials needed by PHT developers, serve as technology repositories, and educate stake holders about these technologies. Public health institutions can serve as an important part of the supportive infrastructure by collaborating with technology developers in elucidating product needs and barriers, facilitating trials of PHTs among their constituents, evaluating the product, advocating for supportive policies, and reengineering innovation into traditional programs and processes.

Training

Given the skills required to successfully develop and implement PHTs, new multidisciplinary academic programs will be needed to train PHT developers. As starting points, emerging technologies should be addressed in health care professional and public health curricula, and training activities should be developed to diversify the skills of existing professionals from the health, technology, and business communities.

Investment

Increased funding for PHT R&D and dissemination is critical to the development of this new field. Most current funding for PHTs comes from government agencies and private foundations, and, given that many PHT concepts are untested in the marketplace, this funding likely will continue in the near future. However, angel investors, venture capitalists, corporations, and other private investors could support PHTs as their commercial value becomes more clearly defined.

Mining Existing Technologies

In addition to developing new PHTs, existing technologies could be repurposed for population health needs as appropriate. The wide array of intellectual property developed under government and corporate R&D and funding programs should be mined for technologies that could be adapted for population health. In the United States, this array includes programs funded by the Small Business Innovation Research (SBIR) program, the Defense Advanced Research Projects Agency (DARPA), the National Science Foundation, the National Institutes of Health, and multinational corporations.

Policy Change

Many PHTs would more likely be adopted widely with supportive health policy change because they have fundamental implications for healthcare and public health systems. For example, outcomes associated with PHTs that provide expert health decision support based on the person's biologic and behavioral profile and environmental context eventually could supersede those outcomes associated with unassisted professional consultation. This process then might set the stage for reimbursement policy changes for effective technologies and realignment of incentives to reward quality and positive health outcomes. Demand for PHTs also could increase to the extent that we can shift from the typical model of medical care insurance to one of health assurance—whereby all people have access to the tools and services they need to stay healthy and recover from illness.

Population health technology is currently a fragmented, under-recognized field that lacks critical mass or infrastructure. Because PHTs are in an early stage of development, their ultimate effect on the health of populations is unclear.

Technology is being woven into the very fabric for which we attain and maintain health and well-being. We cannot predict the future, but, to the extent that we can facilitate the appropriate use of emerging technologies in population health, the more likely we are to become tailors of our destiny.

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