THE FUTURE OF TECHNOLOGY IN HEALTH AND HEALTH CARE: A PRIMER
Questions for discussion

This document presents a number of questions for discussion:

1. It has been said by many that the patient is the most underutilized resource in medicine. How can we accelerate the adoption of virtual care and the expanded capability EHRs so that patients’ time is valued and they are enabled to be more actively engaged in their health and health care?

2. How can we ensure that all Canadians have equitable access to new health technologies regardless of their geographic location and their socioeconomic/cultural characteristics?

3. The private sector clearly recognizes the value of connected health data, as evidenced by recent announcements by companies including Apple and Google. What will it take for Canada’s 70% publicly funded health sector to expand beyond its siloed legacy data systems and invest in big data and analytics?

4. How can Canada better support innovation and commercialization in the health care sector?

5. In an era where health information is being captured and linked across many points of the health care system and beyond, who effectively are the owners and stewards of personal health information?

6. As we move increasingly to connected health data, how can patient privacy be protected such that individuals are not discriminated against on the basis of their environment and/or their health and health care history?

7. Does the manner in which we are educating health professionals affect the health industry’s use of health information? What changes in health education, if any, would promote the more effective use of health information?

8. Do physicians and other health care professionals have access on a daily basis to the health care information they need to provide quality care? What information, if any, is missing or inaccessible, and why?
Over the course of the last century, the medical sciences have made remarkable strides in developing safer and more effective treatments, such as minimally invasive surgery and new drugs that can help mitigate the effects of diseases such as arthritis. While the science of medicine has advanced, the funding, organization and delivery of health care in Canada have not fundamentally changed since the advent of medicare in the 1950s and 1960s. The delivery of health care occurs mainly on a face-to-face basis and is funded on the basis of volume. Internationally there are three major developments that hold the potential to revolutionize the delivery of medicine and health care in Canada:

- **VIRTUAL CARE**
  the use of electronic means to reduce or replace face-to-face interaction;

- **BIG HEALTH DATA**
  the ability to analyze large volumes of different types of data from a variety of sources that are continuously generated; and

- **TECHNOLOGICAL DEVELOPMENTS**
  such as robotics, three-dimensional (3D) printing, virtual and augmented reality, nanotechnology, the Internet of Things (connected devices), health apps that run applications on smartphones and blockchain technology.
Virtual care has been defined as any interaction between patients and/or members of their circle of care, occurring remotely, using any forms of communication or information technologies with the aim of facilitating or maximizing the quality and effectiveness of patient care.¹

Canada was an early pioneer in the development of virtual care through the work of the late Dr. Maxwell House of Memorial University of Newfoundland in the 1970s using telephone technology to provide virtual consultations to remote sites throughout the province.²

Canada has since been far surpassed by other countries in the uptake of virtual care.

In the United States, for example, Kaiser Permanente reported in 2016 that 52% of the 110 million physician–patient interactions in the previous year took place through virtual means.³ By comparison, according to the 2015 Canadian Telehealth Report there were 411,778 telehealth clinical sessions in 2014, representing just 0.15% of the 270.3 million billable services reported by the Canadian Institute for Health Information in 2015–16.⁴

Telehomecare, the use of digital technology to monitor things such as blood pressure, is much less prevalent, with an estimate of just 24,000 Canadians enrolled in such programs between 2010 and 2016. Health care systems in the United States such as Intermountain and Mercy are creating virtual hospitals through extensive use of telehealth technology.⁵,⁶
Electronic communication with patients
While most Canadian physicians are now using electronic medical records (EMRs), electronic communication with patients remains very limited. On the Canadian Medical Association (CMA) 2017 Physician Workforce Survey, 82% of all physician respondents indicated the use of electronic records to enter and retrieve clinical patient notes. However, when asked about the ability of their patients to interface electronically there were far fewer affirmative responses:

- 8.0% indicated that their patients could review information from their health record online;
- 6.5% indicated that their patients could request appointments online;
- 3.3% indicated that their patients could request prescription renewals online;
- 1.8% indicated that their patients could add text to their electronic record; and
- 1.5% indicated that patients could add measurements (e.g., blood pressure) to their electronic record.

Email
The CMA 2017 survey did not ask about email communication with patients but a 2016 survey of Canadians found that 14% said they could consult with their health care provider online and that 55% could not do so but would like to. On a 2015 10-country survey of primary care physicians, Canadian primary care physicians were the least likely to report that their patients had the option of emailing about a medical question; at 15% this was one-third the 10-country average of 47% and well below first-place Switzerland at 80%.

Barriers to virtual communications
There are at least four types of barriers to the uptake of virtual communication between patients and physicians and between physicians and other providers.

Governance of compensation mechanisms. Provincial physician payment systems are still based primarily on face-to-face encounters between the patient and physician. On the 2014 National Physician Survey, fewer than one in 20 physicians reported that they were compensated in any manner for email consultations with patients and just 1 in 10 indicated that they were compensated for email consultations with other physicians. That is starting to change. A recent cross-Canada overview indicates that seven jurisdictions provide for compensation for consulting specialists for electronic consultations, and just two provide compensation for the referring physician. Compensation for e-consultation between physicians and patients remains very limited. The Nova Scotia government has announced a $4.2 million pilot project to deliver telephone and e-health services. Family physicians who enroll their patients in MyHealthNS, the province’s personal health record that enables patients to view test results electronically, will be able to receive up to $12,000 per year for using technology to communicate with their patients.

Private sector and virtual care
Interestingly the private sector is moving into the provision of virtual care by offering services directly to patients and to employers for a fee. For example, getmaple.ca advertises the opportunity to “chat with a doctor in your pyjamas” through online consultations, as well as services including prescriptions and sick notes. The pay-per-visit fee is $49 on weekdays and $79 on weekends and holidays. A family membership costs $50 per month and corporate plans are
available also. In the area of remote monitoring cloudx.com offers remote monitoring of blood pressure, weight and cardiac functions with access to a clinical care team on a subscription basis.

In November 2017 Great-West Life announced that it would offer the services of Quebec-based Dialogue.co to employers in Ontario and Quebec. In March 2018 Sun Life announced that it is the first Canadian insurer to offer virtual health care services to its clients across the country through the Sun Life mobile app, initially through three companies. Internationally the English National Health Service (NHS) has recently launched GP at Hand, a service that enables patients to book appointments and have video consultations with a physician (GP) on their smartphone as well as obtain prescriptions and referrals. The service is provided by Babylon Health. While GP at Hand is free at point of service those who register to use it become de-registered from their existing GP, and if a face-to-face appointment is required the patient has to attend one of the GP at Hand clinics. Since the launch in November 2017, almost 24,000 patients had registered with GP at Hand at the start of April 2018 and the host commissioning group has requested an additional £18 million to be able to meet the demand.

**Regulatory barriers.** A second barrier has been regulatory, in at least two contexts. First, a requirement for an original signature has impeded electronic prescribing, hence the continued reliance on the facsimile machine, or alternatively printing the prescription generated by the EMR, signing it and handing it to the patient. This is about to change, with Canada Health Infoway starting to implement PrescribeIT, a secure e-prescribing solution that will send a prescription directly from the physician's EMR to the pharmacy of the patient's choosing. The other type of regulatory barrier is the issue of the provision of virtual care across provincial boundaries, which may require the physician to be licensed in both the jurisdiction where she/he resides and the jurisdiction in which the patient receiving the service resides.

**Security of personal information.** A third barrier is the concern with the security of email communications, particularly between physicians and patients. The Canadian Medical Protective Association cautions that email and text messaging are often the least secure communication tools, and it notes that protection options available outside the institutional environment can be complex and expensive. Secure messaging systems among health providers are becoming more common.

**Digital divide and access to technology.** A fourth barrier that cuts across these new developments is the “digital divide” that results from the social and cultural inequalities in access to new health-related technologies. There continues to be an access differential between rural and urban areas. In 2014 the Canadian Internet Registration Authority (CIRA) reported that only 85% of Canadians in rural areas had broadband access. In 2016 CIRA reported that Internet service providers in rural communities were 25% slower than those in urban areas. This differential is of particular concern to Indigenous communities. In December 2016 the Canadian Radio-television and Telecommunications Commission ruled that voice and broadband Internet services are basic telecommunications services that should be available everywhere, and investments are being made, which should narrow the gap.
Data from Statistics Canada's Survey of Household Spending show a strong income gradient in home Internet use and spending on mobile wireless services. In 2015 virtually all households in the highest income quintile (98.2%) reported Internet use from home compared with just under two out of three (64.4%) in the lowest income quintile.

Similarly, households in the highest income quintile reported monthly spending on mobile wireless services that was more than three times as great as that of households in the lowest quintile ($140 v. $44). Aside from having less access to the technology, lower income households will be less able to afford the telehealth services that are being offered on a user-pay basis, something that the registrar of the College of Physicians and Surgeons of Nova Scotia has suggested is “dangerous territory.” Public libraries in several Canadian cities have started programs to loan Internet access to persons with low income. There is also an age-related gap in these services. Households headed by a person <30 years old reported spending almost three times as much on mobile wireless services and 1.5 times as much on Internet services as households headed by persons 65+ years old.

Notwithstanding the challenges of telecommunications access in rural and remote areas, Indigenous communities are making significant use of telehealth. Between 2013 and 2015 the First Nations Health Authority in British Columbia expanded its telehealth program significantly, with 128 health care providers serving more than 15,000 Indigenous individuals in 33 First Nations communities by December 2015. In its 2017 report setting out a Health Transformation Agenda, The Assembly of First Nations highlighted the Keewaytinook Okimakanak Telemedicine network that serves 26 remote First Nations in northwestern Ontario. The report was critical about the lack of First Nations engagement in setting e-health priorities and put forward recommendations for dedicated funding and collaboration between governments and First Nations in addressing e-health priorities.

The future of virtual care

There is little doubt that these barriers will be overcome in time. In the future most physicians will be engaged in the provision of virtual care through some means. Nochomovitz and Sharma have proposed a new specialty called the medical virtualist that would describe physicians who spend most or all of their time providing patient care through virtual means. They suggest that specific competencies and curricula will be required, including knowledge of the legal and clinical limitations of virtual care, competencies in virtual examination and “virtual visit presence training.”

Most recently Bhatia and Falk have put forward what they call practical steps toward the “virtualization” of health care in Canada, which include suggestions such as making e-health practice part of accountability agreements and a “digital health by design” lens that would apply a “digital first” philosophy across the payment and delivery system. They do not address the issue of care that crosses provincial boundaries.
The collection of health data has advanced a long way over the past half-century in Canada. Before medicare, the only routinely collected and compiled data were public health data on infectious diseases and vital statistics registrations of death.

Medicare brought about the development of national hospital statistics and physician billing claims data in the 1960s. The 1970s and 1980s brought about national household health surveys. More recently, EMRs have been widely adopted and there are numerous sources of health-related data such as the social determinants of health. Other sources include genetic databases, social media, smartphones and wearable monitors and devices. The magnitude and complexity of data sources and the range of stakeholders engaged in health information are depicted in Figure 1. The term “health data ecosystem” is being increasingly used to describe the complex web of data sources, stakeholders and applications.

Source: Vayena et al. (2018)
Big data has been defined in terms of the three core characteristics of volume, velocity and variety. In the health sector, volume refers to the amount of information available about any encounter and its associated characteristics. Velocity refers to the speed with which data can be generated and exchanged and variety refers to the many forms of both structured and unstructured data that are generated in the health system. Beyond these characteristics, big data also refers to the computational techniques or "analytics" that are used to explore the relationships that exist in the vast amounts of data that are being continuously generated.

There are several applications of big data in health listed below that are not mutually exclusive or exhaustive:

- precision medicine;
- artificial intelligence/machine learning;
- public health/population health management;
- chronic disease management; and
- "real world evidence" of clinical effectiveness.

**Precision medicine**

In his 2015 State of the Union address, US President Barack Obama announced the launch of the Precision Medicine Initiative. Whereas medical treatments have been typically designed for “the average patient,” precision medicine is defined as “an innovative approach that takes into account individual differences in people’s genes, environments and lifestyles.” An early example of this approach was the discovery of blood groups in the early 1900s that led to the cross-matching of blood transfusions.

Precision medicine is reliant on large databases that contain genetic and clinical information that can be analyzed to develop treatment plans that will be effective for particular patients.

The goal of the US All of Us initiative is to assemble a volunteer cohort of more than 1 million Americans who agree to contribute data from various sources. It is expected that this will provide several research opportunities such as the identification of the causes of individual differences in response to commonly used drugs (pharmacogenomics) and the use of mobile health technologies to link physiological measures and environmental exposures with health outcomes. In 2012 the English NHS launched the 100,000 Genomes Project, which will sequence 100,000 whole genomes from NHS patients, with a focus on patients with a rare disease and their families and patients with cancer. The 2015 report of the Advisory Panel on Healthcare Innovation (Advisory Panel) highlighted the potential for precision medicine and it featured Newfoundland and Labrador’s Translational and Personalized Medicine Initiative, a partnership that will integrate a variety of electronic information to target patients and families at high risk for certain diseases, given the concentration of rare genetic disorders on the island. The Advisory Panel recommended the development of a national strategy for the implementation of precision medicine and cited pharmacogenomics and precision cancer care as potential starting points. In January of this year Genome Canada, in partnership with the Canadian Institute for Health Information and others, announced the investment of $162 million in genomics and precision health projects, including a $10.4 million project that will collect genetic information on Indigenous Peoples, and it has just announced a pilot precision health initiative that will establish a national rare disease cohort leading to clinical implementation.
Potential for discrimination

One issue that is raised by genetic testing and precision medicine is the potential for discrimination by employers, insurance companies and others if individuals are required to share their results. The position of Canada’s life and health insurance industry is that while it will not require genetic testing it may ask for the results of tests that have already been done when persons are applying for life insurance greater than $250,000. In May 2017 Bill S-201 received Royal Assent. The bill prohibits requiring an individual to undergo a genetic test or discriminating against an individual for either refusing to undergo a test or refusing to disclose test results. However, shortly after the bill was passed in the House of Commons in March 2017 Justice Minister Jody Wilson-Raybould indicated that she would refer the bill to the Supreme Court to determine its constitutionality. In July 2017 the Quebec government sent a reference to the Quebec Court of Appeal on the constitutionality of the legislation. The CMA has developed comprehensive policy guidelines on direct-to-consumer genetic testing, including a call for regulations based on Bill S-201.

Advances in the use of genetic information for diagnosis and treatment will have implications for medical education and postgraduate training. In her 2016 annual report *Generation Genome*, the UK chief medical officer called for the integration of a “new genomic paradigm” in the training of all clinicians, not just physicians, and noted that it will be essential for clinicians to work with professions not traditionally considered clinical, such as computer scientists, statisticians and data scientists.

Artificial intelligence / machine learning

Artificial intelligence (AI) refers to the use of computers to perform human-like activities such as learning, perception, problem-solving and playing games. AI gained wide publicity when IBM’s Deep Blue computer defeated world chess champion Garry Kasparov in a six-game match in 1997. Machine learning refers to the ability of computers to improve their performance on a task without being explicitly programmed to do so, or as Marr has described it, “machine learning is a current application of AI based around the idea that we should really just be able to give machines access to data and let them learn for themselves.” A highly publicized example of machine learning was IBM Watson’s win on the television game show Jeopardy in 2011. Watson has since been adapted for the health care field in the diagnosis and design of cancer treatment plans. Deep learning is a further extension of machine learning that is based on algorithms modelled after the neural structures in human brains. They are used to recognize patterns in image, sound and text data.
How machine learning will disrupt medicine.

Obermeyer and Emanuel have outlined three key ways in which machine learning will disrupt medicine. First, they suggest that it will improve prognosis by using thousands of predictor variables from electronic records and other sources rather than scoring tools entered by humans.

Second, they predict that it will displace the work of radiologists and anatomical pathologists who focus on the interpretation of digitized images. For example, while a human examines the image of a chest x-ray to make a determination, a machine will treat each pixel on the scan as an individual variable and will organize them into shapes and patterns to make a diagnosis. A further advantage of the machine is that a machine is not affected by fatigue or emotions. The Canadian Association of Radiologists has issued a white paper on AI in radiology with a number of recommendations on education, research and development of clinical applications and implementation. In the field of pathology the digitization of tissue slides facilitates telepathology between sites and facilitates second opinions. Obermeyer and Emanuel also predict that by monitoring streaming physiological data, machines will replace some aspects of anesthesiology and critical care.

Third, they suggest that machine learning will improve diagnostic accuracy by generating differential diagnoses and suggesting high-value tests. They note, however, that the third area will be slower to develop on account of the lack of a clear gold standard for the diagnosis of conditions such as rheumatoid arthritis, which makes it harder to train algorithms.

Computer vision is an emerging application of deep learning. Yeung et al. have described examples of computer vision in the classification of benign versus malignant skin lesions and in the detection of hand-hygiene events in hospital patient rooms.

Char et al. have summarized the profound implications of big data for medicine as follows:

“the collective medical mind is becoming the combination of published literature and the data captured in health care systems, as opposed to individual clinical experience.”

Public health / population health management

Big data are foundational to the advance of the discipline of public health and the rapidly emerging field of population health management. Since its origins, the focus of public health had been on the detection of, prevention of, and response to infectious diseases, the celebrated example being John Snow’s mapping of cholera incidence around the Broad Street water pump in London, England. Latterly public health has expanded its focus to include the promotion of healthy lifestyles and the role of non-medical determinants of health.
Population health management (PHM) has been defined as “the aggregation of patient data across multiple health information technology resources, the analysis of that data into a single, actionable patient record, and the actions through which care providers can improve both clinical and financial outcomes.”

PHM has become increasingly prominent since the passage of President Obama’s Patient Protection and Affordable Care Act (PPACA) in 2010. The PPACA has enabled the sharing of risk between payers and providers in the US Medicare program, hence it is in the providers’ interest to be able to reduce the risk of their patient populations in incurring health care costs.

**Range of data expanded**

The range of data sources available to public health practitioners has expanded considerably beyond reports of notifiable diseases and vital statistics to include data linkages between health and census and administrative data, electronic health records (EHRs) and social media. Until recently epidemiologists had to rely on ecological studies using aggregate data. The power of big data is shown in a 2016 study by Chetty et al. of the association between income and life expectancy in the United States. Their study linked income from de-identified tax records with mortality data from the US Social Security Administration, thus providing 1.4 billion person-year observations over 1999–2014. The granularity of the analysis uncovered local variation in the mortality-income relationship, suggesting the need for local policy responses and also suggesting implications for the Social Security program.

**Use of social media for disease surveillance**

There have been several efforts to use social media data for disease surveillance, particularly for influenza. In 2008 Google launched Google Flu Trends, based on the analysis and modelling of flu-related search terms entered on the search engine. The system was expanded to 29 countries and was performing well, but the 2013 flu season arrived early in the United States and Google Flu overestimated the peak by 140%. The program was discontinued after 2015. Lazer et al. highlighted several lessons from this experience including the need for transparency and replicability and the potential value of complementary "small data" sources. Wiens and Shenoy have provided several examples that outline the potential for machine learning to improve patient risk stratification for specific infections, to understand the relative contribution of specific risk factors and to predict the spread of infectious diseases.
Electronic health records and billing claims

In the area of PHM, big data sources such as EHRs and billing claims are being used in the United States to identify patients with multiple conditions who are at risk of high frequency health care use and who might benefit from interventions such as longer care coordination. The potential for Canada has been illustrated by the work of Wodchis and colleagues, who have shown that in Ontario in 2007 the top 1% (in terms of frequency of use) of patients used 34% of publicly funded health resources.

How big data is impacting public health roles

Big data are leading to subspecialization in public health and PHM. The American Board of Preventive Medicine has introduced a subspecialty in clinical informatics that is intended to “analyze, design, implement and evaluate information and communication systems that enhance individual and population health outcomes, improve patient care and strengthen the clinician–patient relationship.” In PHM an emerging role is the Chief Population Health Officer (CPHO). This position is generally responsible for the development of a health system's PHM strategy. The CPHO profile might include a medical degree, public health experience, membership in a large physician group, an advanced degree in business or health administration and experience in team-based care. More generally, in a review of 271 PHM job postings in the United States across a range of positions, Meyer noted the frequently mentioned requirements of analytics expertise and the understanding of various data sources.

Chronic disease management

Chronic disease management can be defined as the “ongoing care and support to assist individuals impacted by a chronic health condition with the medical care, knowledge, skill and resources they need to manage better on a day to day basis.” It is certainly related to PHM activities but is singled out here because the surveillance and treatment of chronic diseases has not received the attention that has been accorded more fatal diseases such as heart disease and cancer.
Indeed, the United Nations General Assembly only adopted its declaration on the prevention and control of "non-communicable diseases" in 2011, in which it called on governments to give greater priority to surveillance, early detection, screening and treatment of non-communicable diseases.74

In 1976, James Fries, who later became famous for the "compression of morbidity" thesis predicting that morbidity would become concentrated at the end of the lifespan,75 envisioned a future where computerized databanks would help the clinician by identifying less productive activities in medicine, by supplying the missing clinical study and by providing decision support for management of the individual patient.76 A decade later Fries et al. set out guiding principles for what would now be viewed as a rudimentary prototype of the American Rheumatism Association Medical Information System (ARAMIS) that would compile longitudinal data on patients with rheumatic disease across 17 centres, depicted in Figure 2.77

In 2005 Bruce and Fries reflected on the success of ARAMIS and how it was advancing in the area of patient-reported outcome measures.78

Figure 2: Core elements of the American Rheumatism Association Medical Information System, 1986

In Canada, the Canadian Primary Care Sentinel Surveillance Network (CPCSSN) was established in 2008 by the College of Family Physicians of Canada with a grant from the Public Health Agency of Canada (PHAC) and is now maintained in the Centre for Studies in Primary Care at Queen’s University. This began with seven existing academic research networks and data collection was based on de-identified information contributed by family physicians from their EMRs on eight chronic diseases and neurologic conditions (chronic obstructive pulmonary disease, depression, diabetes, hypertension, osteoarthritis, Alzheimer disease and related dementias, epilepsy and Parkinson disease).79 As of May 2016 there were nearly 1,200 participating family physician and nurse practitioner sentinels from more than 200 practices with more than 1.5 million patients, of whom roughly 700,000 had had at least 1 visit in the previous 12 months. The data are drawn from almost the entire medical record and include elements including demographics, diagnoses, physical measures, lab results and other utilization variables. Patient and provider confidentiality are paramount and CPCSSN has developed mechanisms to address data quality. CPSSN data are being used in research studies at the national, regional and local levels and are being linked to other sources. They are also being used to develop EMR specifications of other conditions such as childhood asthma and chronic kidney disease.80 Sustaining funding for CPSSN remains a challenge, and since 2015 funding has been received from a number of sources.
In terms of the application of big data to chronic disease management beyond surveillance, a review by Bhardwaj et al. has documented examples where they have been used to reduce hospital readmissions, to improve diagnostic accuracy and risk prediction and to develop treatment guidance leading to improved patient outcomes at lower cost.\(^8\) Zhang and Padman have developed predictive clinical pathways for patients with chronic kidney disease from EHR data.\(^8\)

**“Real world evidence” of clinical effectiveness**

The randomized controlled trial (RCT) has long been the gold standard for testing the safety and effectiveness of new drugs and treatments. The growing availability of massive amounts of data from EHRs, claims data and other sources (referred to as real world data [RWD]) has raised the prospect of the use of observational data to generate what has been termed "real world evidence" (RWE). A review by Singh et al. of the uses of RWD in clinical research and drug development has identified examples where they have been used to develop new understandings of a disease and disease associations, to discover new markers for patient stratification and targeted therapies, to identify formerly undiagnosed patients with a disease, and to conduct drug safety studies.\(^8\) In 2017 the US Food and Drug Administration issued guidance on the use of RWE in regulatory decision-making for medical devices,\(^8\) and it is developing a regulatory framework to evaluate how RWE can support the approval of new indications for drugs and the conduct of post-approval studies.\(^8\)

**Implications of big data for physicians**

It is evident that the breadth of the emerging and potential applications of big data in health is going to have implications for all physicians, not just for existing disciplines such as radiology/pathology and the emerging subspecialties in public health. In 2014 the Association of Faculties of Medicine of Canada and Canada Health Infoway produced a set of e-health competencies for undergraduate medical education mapped onto the seven CanMEDS roles.\(^8\) Also in 2014 an e-health expert working group led by Dr. Kendall Ho of the University of British Columbia developed a proposed set of competencies for each of the CanMEDS roles in the postgraduate training system as part of the 2015 revision.\(^8\) While these appeared in a very limited way in the final document\(^8\) they provide an excellent foundation for future iterations.

One issue that is starting to receive attention in the health sector in Canada is "cybersecurity," a term that refers to the ability to protect computer networks, programs and databases from digital attacks, more commonly referred to as "hacking." There has been particular concern about "ransomware," a malicious software (malware) that is used to take over a computer system and deny access to data unless a ransom is paid. In May 2017 the malware virus called Wannacry attacked hospitals and other organizations in almost 100 countries. The virus affected numerous NHS health facilities in England including hospitals and GP practices\(^8\) and at least one Canadian hospital.\(^8\) The NHS cancelled almost 20,000 appointments and operations as a result. While much of the attention to date has focused on hospitals, a summer 2017 survey of US physicians found that more than four in five had experienced some form of cyberattack, the most common being "phishing" — clicking on a malicious link in an email.\(^8\) Zelmer has reported that cybersecurity awareness preparedness varies widely across health care settings in Canada.\(^8\)

Another consideration is the amount of time that physicians and other clinicians have to spend entering data in electronic medical and health records. A 2016 study by Sinsky et al. of US physicians found that for each hour of clinical time with patients, physicians spent almost two hours on EHR and desk work during the clinic office day, plus an additional one to two hours in the evening, most of which was spent using an EHR.\(^8\) Wachter and Goldsmith have highlighted the current state of EHRs as a source of physician burnout that needs to be fixed through voice recognition, AI and other means.\(^8\)
TECHNOLOGICAL DEVELOPMENTS

Technological developments in a number of areas will have major implications for the delivery of health care. Some have been around for some time but have yet to become mainstream, while others are at very early stages.

Health apps
A health app is a health service that is provided through a computer software program that is downloaded on a mobile device such as a smartphone.

- In 2017 it was estimated that 325,000 mobile health apps were available.95

Health apps are closely linked to the concept of mHealth, defined by the World Health Organization as "medical and public health practice supported by mobile devices, such as mobile phones, patient monitoring devices, personal digital assistants (PDAs), and other wireless devices."96 Health apps serve many different functions, including promoting physical fitness and health living, facilitating remote monitoring, providing medication and appointment reminders, and serving as diagnostic aids and as reference tools.97
A 2017 survey of Canadians found that 32% had reported the use of at least one mobile app for health-related reasons in the past three months. Those under age 35 were more than twice as likely (51%) to have used a mobile app as those aged 55–64 (23%). Among those who had used an app for health reasons, the most frequently cited purposes were in the area of regular physical activity (64%), followed by nutrition and eating habits (41%), weight-related information and sleep (both 36%). Purposes less frequently cited included monitoring medication use (9%), diabetes/other metabolism-related conditions (6%) and tobacco dependence (5%). Just over one-third (35%) of the users reported sharing the data captured by the health app with other people, and they were most likely to share with other family members (61%), friends (50%) or their doctor (34%).

From the physician perspective, the 2014 National Physician Survey found that one in six (17%) Canadian physicians reported that they recommend mobile apps to their patients and the most frequently cited purpose they did so was for self-management for a health condition (70%), followed by health monitoring (60%) and health information (42%). The CMA has set out guiding principles for physicians recommending mobile health apps to patients that include:

- endorsement by a recognized medical or professional organization;
- usability;
- reliability of information;
- privacy and security; and
- avoidance of conflict of interest.

Apps are being increasingly used in the delivery of care. The GP at Hand service described above is powered by the Babylon Health app, which asks patients about their symptoms and advises them if they need a medical consultation. mHealth holds the promise of making health care more accessible in countries with scarce health human resources. Babylon’s declared mission is to “put an accessible and affordable health service in the hands of every person on earth” and they have recruited a team from more than 60 countries.

Babylon partnered with the government of Rwanda to launch an initiative in 2016 with 25 clinicians supported by 20+ back office staff that registered 10% of adult Rwandans in its first 6 months.

The proliferation of health apps raises questions about their safety and regulation. In April 2018 Health Canada announced the establishment of a Digital Health Review Division that will have increased review capacity for medical devices that integrate digital health technologies. The areas of focus will include wireless medical devices, mobile medical apps, telemedicine, software as a medical device, AI, cybersecurity and medical device interoperability. The intent of establishing the new division is to improve access to new digital technologies that have rapid development cycles.
Robotics

While many people became acquainted with robots through human-like machines in science fiction movies, a robot is more generally defined as “a machine capable of carrying out a complex series of actions automatically, especially one programmable by a computer.” Health care is one of the leading industries in the adoption of robotics. They are being used in surgery, including remote surgery, they are being used in the provision of diagnosis and treatment in remote locations, and they hold promise as wearable devices that can assist people with activities of daily living.

Since the 1990s robot-assisted surgery has become widely adopted in minimally invasive laparoscopic surgery. One celebrated instance occurred in 2001 in “Operation Lindbergh,” where a surgeon in New York removed the gallbladder of a 68-year-old woman in Strasbourg, France, following a successful demonstration on six pigs. It took 16 minutes to set up the robotic system and 54 minutes to carry out the operation. In 2003 Dr. Mehran Anvari led the establishment of the Centre for Minimal Access Surgery (CMAS), which developed a remote surgical service between St. Joseph’s Hospital in Hamilton, Ontario, and the North Bay General Hospital, 400 km to the north. CMAS has become a leader in laparoscopic surgery and has trained an estimated 9,000 surgeons, fellows and residents in these techniques.

Presently the field of robotic surgery has been dominated by the da Vinci Surgical System (da Vinci), currently in its fourth generation, which has almost 4,000 installations worldwide. The da Vinci system has four arms that are controlled by a surgeon using joysticks on a console. In 2016 it was reported that da Vinci had been used in 563,000 operations in the United States, of which 44% were in gynecology, 33% in general surgery and 19% in urology.

Outside the United States, da Vinci was used in 190,000 operations, the majority of which were urological. Robotic surgery is more expensive; the equipment costs more than $2 million and annual maintenance can cost up to $170,000. In 2017 the Ontario Health Technology Assessment Committee reported that robot-assisted prostatectomy cost $6,234 more than open radical prostatectomy, and with a gain of 0.0012 life-years represented a cost of $5.2 million per quality-adjusted life year gained. Fong et al. have contrasted the increased cost of robotic surgery with the experience in the automotive manufacturing sector, where robots speed up the process and reduce costs. Rao has speculated that the entry of new robotic systems into the market will provide competition to the da Vinci system.

At least two Canadian jurisdictions are using remote-presence robots to deliver health care in remote communities.

In 2010–11 an RP-7 remote presence robot was deployed in a pilot project at a health clinic in Nain, Labrador, 367 km north of the closest referral centre in Happy Valley-Goose Bay. The RP-7, soon nicknamed Rosie the Robot by the staff, is remotely controlled and is equipped with two-way audiovisual communication and a digital stethoscope. An evaluation showed high satisfaction among physicians, nurses and patients, and there was a significant avoidance of air transport to the referral centre. Saskatchewan has also been piloting the use of remote presence robots in northern communities. A pilot project with pediatric patients in Pelican Narrows found that 63% of the children could be treated in their own community. In October 2017 it was announced that two additional robots would be deployed to provide remote youth mental health services to help address the growing frequency of youth suicide. A recent report described how a pediatrician in Saskatoon was able to diagnose pneumonia in an infant using the robot, enabling her to be hospitalized locally rather than being flown to Saskatoon.
There is also considerable research and development underway in the area of robotic exoskeletons.119 These have potential to assist walking in persons with spinal cord injury120 and for the prevention of falls in elderly persons.121

3D printing
3D printing is defined as “the process of making a physical object from a three-dimensional model, typically by laying down many thin layers of a material in succession.”122 It was invented in the 1980s and research and development has been ongoing, but there has been an explosion of interest in health care applications over the past several years. Prosthetics, and hand prostheses in particular, have received considerable attention. In comparison with the myoelectric prosthetic hand, the 3D-printed hand is lightweight and much less costly. A study by Lee et al. found that the 3D-printed hand had lower grip strength and decreased dexterity than the myoelectric hand; however, the cost of the myoelectric prosthesis used in the study was US$13,000 and it took 2 weeks to fabricate it compared with US$440 and 4 days for the 3D-printed one.123 Low-cost 3D-printed hands would offer a distinct cost advantage to growing children. It is estimated that there is considerable potential for 3D-printed prostheses to benefit some 30 million people worldwide, particularly those in low-income countries.124 Enabling the Future is an international network of 7,000 volunteers who have used 3D printers to make some 2,000 devices that have been given to individuals in more than 45 countries.125

3D printing is also being used to create patient-specific models of cardiovascular structures that assist in the planning of cardiovascular procedures.126 At some point in the future it is anticipated that 3D bioprinting might be used to build replacement organs such as kidneys.127 A research group at Harvard reported in 2016 on a bioprinting method for creating renal proximal tubules, a step toward the eventual bioprinting of a human kidney.128 3D printing is also expected to have applications in the area of pharmacueticals, including early-phase drug development, pediatric and geriatric populations and medications with complex dosage regimes.129

Nanotechnology
Nanotechnology is “the science and engineering involved in the design, synthesis, characterization and application of materials and devices whose smallest functional organization in at least one dimension is on the nanometer scale (one billionth of a meter).”130 To put this in perspective a human hair is approximately 80,000 nm wide. Research and development in nanotechnology and medicine has focused on drug delivery and regenerative medicine.

In the area of drug delivery, nanotechnology has the potential for accurately targeting drugs and also for their controlled release. The drugs are delivered by attaching them to biodegradable nanoparticles.131
Research is also underway on the potential for nanotechnology to deliver drugs across the blood-brain barrier to treat diseases of the central nervous system and brain tumours. In the area of cardiovascular disease and the treatment of thrombosis Giménez et al. have noted that addressing a clot with nanoparticles loaded with tissue plasminogen activator (tPA) might be a more effective means of clot dissolution than intravenous infusion of tPA.

Nanomedicine describes the application of nanotechnology to regenerative medicine, the science of replacing tissues and organs. In the field of orthopedics, research and experimentation are underway in cartilage replacement and cartilage tissue engineering. A 2016 review suggests that in the future nanomedicine will contribute to longer lasting implants and lower infection rates but concludes that it is still in a stage of infancy.

**Augmented reality / virtual reality**

Augmented reality (AR) is "a technology that superimposes a computer-generated image on a user’s view of the real world, thus providing a composite view." Virtual reality (VR) can be defined as "the computer-generated simulation of a three-dimensional image or environment that can be interacted with in a seemingly real or physical way by a person using special electronic equipment, such as a helmet with a screen inside or gloves fitted with sensors.

Both AR and VR have growing applications in surgery and medical education and training. In the area of surgery, Yoon et al. reviewed 37 studies of live human operations involving the use of AR in "head up" displays such as Google Glass. The head up display enables the surgeon to concentrate more on the patient by not having to look elsewhere for visual displays. Across the studies the most common uses of the head up device were live streaming from endoscopy, images from intraoperative magnetic resonance imaging (MRI) or computed tomography (CT), monitoring of vital signs, and display of preoperative MRI or CT images. They noted that this could be further improved if holographic images could be projected onto the surgical field, and they also stressed the need for outcome studies.

At present a key application of VR in surgery has been in the use of VR simulators for training in laparoscopic surgery. A more recent application of VR and AR is the Virtual Interactive Presence and Augmented Reality (VIPAR) system for remote surgical assistance. This comprises a local and a remote station, each of which has two cameras for stereoscopic capture and a high-definition viewer that displays a virtual field. This enables the remote expert to see what the local surgeon is seeing and the local surgeon to see what the remote expert is doing. AR has also had applications in training in neurosurgical procedures and echocardiography.

There have been a number of studies of the use of VR in the management of pain. While the mechanism through which VR reduces pain perception is not fully understood, "VR is thought to create an immersive distraction that restricts the mind from processing pain."
Internet of Things

The Internet of Things (IoT) can be defined as a collection of "smart" devices and "wearables" that collect and communicate data. The previously cited 2017 survey of adult Canadians found that one in four (24%) owned at least one smart connected device for health and well-being, although just 14% said that they both owned and used them. Of those both owning and using a smart device the majority (70%) reported owning just one, and most (84%) have been using them for less than two years. Among those owning a smart device the most frequently owned types included a bracelet, wristband or watch (88%), followed by a bathroom scale (21%) and pedometer (13%). Just 4% reported owning an item of intelligent clothing. Of those owning and using smart devices 69% somewhat or strongly agreed that they have maintained or improved their health status by using smart devices and 58% agreed that they feel more confident taking care of their health on account of using smart devices, while just 41% agreed that smart devices enable them to have more informed discussions with their doctor. More than eight out of 10 owners and users (85%) indicated that they intend to continue using their smart devices for their health and well-being.

Haghi et al. have reviewed the current state of the art in smart clothing. The sensor positions and their tasks are summarized in the table below.

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Spot on body</th>
<th>Sensor’s task</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pulse</td>
<td>Wrist</td>
<td>Photoelectric volume pulse wave signals measurement</td>
</tr>
<tr>
<td>Body temperature</td>
<td>Under ar easel</td>
<td>Body temperature</td>
</tr>
<tr>
<td>ECG</td>
<td>Chest and ribs</td>
<td>Vital sign</td>
</tr>
<tr>
<td>Myocardial</td>
<td>Left chest</td>
<td>Complement of ECG, measure the body's myocardial signal</td>
</tr>
<tr>
<td>Blood oxygen</td>
<td>Triceps muscle of left or right arm</td>
<td>Measure the volume of oxygen in blood</td>
</tr>
<tr>
<td>EEG</td>
<td>Left or right forehead and left or right back side of head</td>
<td>Detect abnormalities related to electrical activity of the brain</td>
</tr>
</tbody>
</table>

ECG: electrocardiogram, EEG: electroencephalogram

Source: Haghi et al. (2017) 143

They conclude that thus far no efficient solution has emerged for comprehensive monitoring of gas detection, motion tracking and vital sign monitoring in a single device.143

Perhaps the latest smart device is the first digital drug, which was approved in the United States in 2017. This is an antipsychotic pill with an embedded that mixes with stomach acids when swallowed and sends a signal to an adhesive patch on the patient that records the dosage and time of ingestion and relays it to a smartphone app.144

Yin et al. have presented the concept of a smart rehabilitation system that links wireless monitoring devices to all the health care resources in the community, including hospitals, rehabilitation centres, physicians, nurses, ambulance and assistive devices, which would all connect to a central server.145
Blockchain technology

Blockchain technology has its origin in a 2008 paper published under the pseudonym of Satoshi Nakamoto that proposed an electronic payment system named the “bitcoin” that enables transactions without the need for a central authority by establishing a chain of digital signatures that record all transactions in the chain through a “distributed ledger” that is shared across a network of computers.\(^{146}\)

To date most of the activity around blockchain has been in the financial services sector, but several applications have been envisioned for the health sector.

In 2016 the US Office of the National Coordinator for Health Information Technology issued a challenge to develop white papers on applications of blockchain technology to EHRs. The 15 papers that were awarded covered a range of topics such as national interoperability, alternative payment models and patient-reported outcome indicators for mental health.\(^ {147}\)

The key health care applications that have been identified so far are medical record management, claims processing and clinical/biomedical research. Kuo et al. have enumerated the potential advantages of blockchain technology in each of these areas against what they consider the core features of the blockchain.\(^ {148}\) The example for medical record management is summarized as follows:

<table>
<thead>
<tr>
<th>Core blockchain feature</th>
<th>Benefit to medical records management</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decentralized management</td>
<td>Patient owns and controls access to their health care data – facilitates transfer to other providers.</td>
</tr>
<tr>
<td>Immutable audit trail</td>
<td>Medical data cannot be changed.</td>
</tr>
<tr>
<td>Data provenance</td>
<td>Medical records are source verifiable.</td>
</tr>
<tr>
<td>Robustness/availability</td>
<td>Lowered risk of patient recordkeeping, and distributed network means that no single institution can be attacked to obtain medical records.</td>
</tr>
<tr>
<td>Security/privacy</td>
<td>Data are encrypted and can only be decrypted with the patient’s private key.</td>
</tr>
</tbody>
</table>

Source: Table 1 in Kuo et al. (2017)\(^ {146}\)

A recent survey of 200 health care executives in 16 countries found that 16% were expecting to have a commercial blockchain application in place in 2017.\(^ {149}\)
Estonia saw the potential for blockchain as early as 2011, and in 2016 it signed with the firm Guardtime and its blockchain technology to secure the EHRs of its 1.3 million citizens. In the United States the Car-eX Blockchain Platform enables patients to manage their health information, seek virtual care and pay for a full range of health care services using tokens on a blockchain. In Canada it was recently announced that the Peterborough, Ont., Public Health Department has partnered with HealthSpace Data Systems to enable public health inspectors to transmit their inspection reports to the blockchain.

**Summary**

In summary, there is little doubt that the emerging confluence of health information and other technologies is going to radically reshape the delivery of health care and that the experience of other countries would suggest that Canada has some catching up to do.

In 2016 the Standing Senate Committee on Social Affairs, Science and Technology undertook a study on robotics, AI and 3D printing, with a focus on their application to direct and indirect patient care and home health care. They heard from a number of Canadian leaders in this area about the potential of these technologies but also about the challenges that companies face in trying to commercialize innovations in Canada, echoing the findings of the 2015 Advisory Panel. The 2017 Senate report set out 14 recommendations calling for the convening of a national conference on the application of these technologies in health care and the subsequent striking of expert groups that would address a number of issues in concert with the relevant ministries and research granting councils. The issues they listed include:

- ethical considerations;
- commercialization concerns;
- health care delivery renewal;
- rural and remote health care delivery;
- equity of access to emerging technologies;
- workforce adjustments;
- education and training requirements; and
- regulatory oversight.

In April 2018 Health Minister Ginette Petitpas Taylor submitted a comprehensive response to the report, highlighting the activities and recent investments of the government ministries and agencies on each of these issues.


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