The future of medicine: From predictions in 2000 to realities in 2025

In 2000, Dr Cairns predicted what medicine would look like in 2025. Here, he reflects on those predictions.

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Reflecting on my bird's-eye view from 2000 of what the next 25 years of medicine might look like [*BCMJ* 2000;42:241-242], I have observed that several of my predictions have been fulfilled to varying extents, some have not materialized, and some unanticipated developments have assumed importance. The breakneck pace of change has accelerated.

Genomics

Human genome

Shortly after publication of my article in June 2000, Bill Clinton and Tony Blair announced the emergence of a rough draft of the human genome from the Human Genome Project, but it was not until August 2023 that the complete genome was published, somewhat later than many had predicted.[1] Immediate medical applications included development of cancer and other disease therapies directed at various mutations; design of pharmaceutical agents; and development of genetic testing for predisposition to many disorders, including breast cancer, cystic fibrosis, and hepatic diseases. Research into the causes of a variety of cancers, Alzheimer disease, and more has been facilitated. The availability of genomic information and the potential for its use has given rise to multiple ethical and legal dilemmas, some of which were anticipated, as demonstrated by the allocation of 5% of the Human Genome Project's total budget to address ethical, legal, and social implications.

Precision medicine

Implicit in my 2000 predictions was the development of what has come to be called "precision medicine," an approach that selects therapies based on the detection of certain genes, proteins, or other substances in a potential patient that are likely to influence the patient's response to given therapeutic agents.[2] Inherent to the strategy of precision medicine is the availability of biomarkers that can be detected in blood or other tissues and used to identify cells with susceptibility to given therapeutic agents. These approaches are now highly developed for the selection of cancer therapies. Whereas traditional chemotherapies are nonselective and toxic not only to malignant cells but also to all rapidly proliferating cells, targeted therapies involve identifying the unique features of cancer cells that help them grow, divide, and spread. These features can then be targeted with specific therapeutic agents designed to disrupt or block their functions.

Pharmacogenomics

Pharmacogenomics, the study of how genes affect a person's response to drugs, has progressed enormously in the past 25 years.[3] For any given drug, some people will respond fully, others only partially or not at all, and still others may experience undesirable, even fatal, side effects. The National Institutes of Health Genetic Testing Registry now maintains a database of laboratories able to test for genes and proteins to allow better targeting of therapies and identify persons at high risk of selected adverse drug reactions. Therapies selected based on pharmacogenetic studies are now in widespread use, and such strategies will multiply as basic research and clinical trials evolve.

Genetic engineering

Genetic engineering, the artificial manipulation, modification, or recombination of DNA or RNA to modify an organism, has been with us since the late 1960s. In 2000, the repertoire of genetically engineered drugs included only a few agents, including tissue-type plasminogen activator, insulin, and human growth hormone. Developments in the last 25 years have been explosive, and there are now huge numbers of such drugs available, as well as many drug delivery systems developed using genetic engineering techniques.

The spectacularly rapid development

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of mRNA-based vaccines,[4] which curbed the devastation of the COVID-19 pandemic and could be quickly modified to deal with viral mutations, was possible because of the discoveries of Katalin Karikó and Drew Weissman, who received the 2023 Nobel Prize in Physiology or Medicine. The lipid nanoparticle encapsulation process developed by University of British Columbia scientist Pieter Cullis is an essential component of the vaccines, allowing entry of the mRNA into human cells. This mRNA-based technology promises to offer a whole new family of vaccines, as well as strategies for targeting malignant cells.

Gene editing technologies[5] allow highly specific changes to be made in the DNA of a living organism. The most recent and promising of these technologies is CRISPR-Cas9, the discovery and development of which led to the award of the Nobel Prize in Chemistry to Jennifer Doudna and Emmanuelle Charpentier in 2020. This technology could be used to modify defective genetic codes in mono- or multigenetic diseases and to treat infectious diseases, autoimmune disorders, and cancer. ClinicalTrials.gov currently lists 60 trials using CRISPR-Cas9 technologies. There are many hurdles to address, including the immunogenicity of the administered cellular materials and a variety of complex ethical issues, but these are likely to be overcome as research surges forward.

Transplantation

I predicted significant progress in human tissue and organ replacement, but progress on this front has been rather slow. The number of annual organ transplants worldwide increased to about 157 000 in 2022[6] (2936 in Canada),[7] with a 23% increase from 2009 to 2018, and short-term survival has improved modestly. However, overall success is limited by chronic rejection and the availability of viable organs. In Canada in 2018, 223 people died while awaiting an organ for transplant, and there were 4351 people on the transplant wait list. There has been progress in artificial organ technology, but there has been no long-term survival of a patient dependent on an implanted artificial organ. Xenotransplantation (the experimental process of transplanting organs across species) has been tried in one approved instance. The problems of rejection, donor infectious agents, and species-specific organ function are the focus of ongoing research.

The transplantation of hematopoietic stem cells obtained from bone marrow, peripheral blood, or umbilical cord blood has been available for many years for treatment of leukemias and lymphomas and for selected postradiation and postchemotherapy cancer patients. More recently, pluripotential stem cells have been recovered from embryonic tissue (the inner cell mass of the blastocyst) and a number of adult tissues, including skin and bone marrow. Differentiated cells in such tissues have also been deprogrammed back to a pluripotential state (induced pluripotent stem cells). Although only hematopoietic stem cell transplantation is currently approved by the US Food and Drug Administration for human clinical use, there are many stem cell clinics marketing unproven stem cell therapies in the US and worldwide. Active research is exploring these therapies for neurodegenerative diseases, diabetes, heart disease, and many other conditions, and it seems likely some of this work will eventually bear fruit.

Health care system

In 2000, I predicted that BC health care would come to be provided in a setting of more planned and all-encompassing models. Dramatic changes began in December 2001, with the consolidation of 52 health authorities into five geographic governing authorities and the Provincial Health Services Authority (PHSA). Each regional health authority is responsible for planning and delivering health care services within its geographic area. The PHSA oversees coordination and delivery of highly specialized services like cancer care and transplantation provincewide. In 2013, the First Nations Health Authority was created.

There has been enormous progress in the development and deployment of electronic health records in BC. The Clinical & Systems Transformation project[8] is a multiyear project on which Vancouver Coastal Health, the PHSA, and Providence Health Care have cooperated to establish common clinical and process standards (e.g., workflows, order sets, clinical guidelines, integrated care plans) and a common electronic health record system. A common clinical information system (Cerner) has replaced multiple aging systems. Medications are now supplied to the bedside as prepackaged, barcoded, single-unit doses, which can be barcode scanned and administered directly to the patient or resident without additional preparation. As of September 2024, implementation has been completed in most acute and residential care facilities within Vancouver Coastal Health and in PHSA facilities in the Vancouver Coastal Health region.

My prediction regarding improved access to patient medical data has been realized. In 2013, the BC Services Card replaced the CareCard. It can be used to access a variety of BC government and agency services. The Health Gateway app allows BC residents to securely access their health data (e.g., medications, vaccinations, medical visits, hospital stays), along with selected personal nonhealth data held in provincial and federal government repositories. This system can be challenging to the many individuals who are inexperienced or incapable of using modern electronic systems, but it represents a huge advance for those who have these capabilities.

There has been substantial progress deploying electronic health records to individual physicians. Implementation in BC has been facilitated by the outstanding web-based guidance available from the Doctors Technology Office, a joint initiative of Doctors of BC and the provincial government. A further major impediment continues to be Canada's disparate network of 14 essentially independent health care systems (10 provincial, 3 territorial, and 1 federal) and their lack of interoperable electronic health records. In 2001, the federal government established Canada Health

Infoway, an independent, not-for-profit corporation charged with transforming Canada's health care system through digital health. Although progress has been slow, an independent performance evaluation in 2018 reported that Canada Health Infoway has greatly contributed to more timely delivery of health care, increased productivity and interoperability, and improved access to and sharing of information. A 2024 survey of Canadian physicians found that 95% of respondents used electronic health records to enter and retrieve clinical patient notes, a dramatic increase from 39% in 2010, although they experience major challenges using these systems, and burnout is a threat to progress and even sustainability. A November 2024 report[9] acknowledged significant funding (over $3 billion to date) and effort but identified poor interoperability of data systems, even within cities and provinces, and emphasized that more commitment and collaboration was required from federal, provincial, and territorial governments to accelerate progress.

Medical education and research

In relation to population, in 2000, BC had fewer medical students and fewer postgraduate trainees (residents) than any other Canadian province[10,11] and was able to satisfy only 25% of the annual need for new physicians in the province. I predicted that the BC government would begin to take responsibility for educating the physicians needed by British Columbians, and the situation has changed profoundly, beginning in December 2000 with substantial new provincial funding announced to put more doctors, nurses, and other health professionals into the health care system. In spring 2001, the new provincial government committed to double BC's enrolment of medical students (and residents) in a distributed program centred at the University of British Columbia and in partnership with the University of Northern British Columbia and the University of Victoria. The dramatically enlarged and provincially distributed medical education enterprise has become an internationally recognized model. In 2024, there were 340 students in the first-year medical class (compared with 120 in 2000), and UBC now graduates more MDs annually than any other Canadian university (298 in 2021).[10] Enrolment in Canadian medical schools has almost doubled since 2000.[10]

As I predicted in 2000, not only has medical education expanded, but it has also evolved significantly to better equip future doctors for practice. In their first year, medical students begin clinical experiences in doctors' offices and community and hospital clinics. With the new distributed programs, medical students and residents experience real-world settings and build relationships with communities province-wide. Their educational programs are built on problem- and case-based paradigms that feature realistic patients and emulate clinical practice. Accreditation standards require each medical school to commit to addressing the priority health concerns of the population it serves and to demonstrate that its admissions processes, curricular content, and types and locations of educational experiences produce MD graduates who are socially accountable. The UBC Faculty of Medicine recently reviewed its 56 learning cases for appropriateness in issues of equity, diversity, and inclusion, making changes as needed. The demographics of BC's medical students are changing:[12] about 60% of students are women (compared with about 50% in the early 2000s), the mean age has risen to about 25 years, only about 9% have no university degree (27% in 2012), and 57% attended secondary school in locations other than Vancouver (50% in 2012). Between 1954 and 2000, there were five UBC MD graduates of self-identified Indigenous ancestry. Since implementation of the Indigenous admissions pathway in 2002, there have been more than 120 additional Indigenous MD graduates.

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Canada is still trying to recover from cutbacks in medical student enrolment in the 1980s prompted by flawed predictive data that failed to adequately account for population aging, advances in medical therapies and surgical techniques, and changes in the sex distribution and practice patterns of physicians. The ratio of doctors per 1000 population increased from 2.0 in 2000 to 2.7 by 2019, but the OECD average is 3.4, and Canada's ratio was lower than that of every European country included in the rankings.[13] In 2023, 17% of Canadians did not have regular access to a primary health care provider,[14] and access to specialists and surgical procedures was problematic.

Some of the problems of access to primary care may be alleviated by measures I mentioned in 2000 that are now implemented in BC and several other provinces, including expanded education and practice entry of nurse practitioners and midwives and substantial expansion of the scopes of practice of pharmacists. Alternatives to the fee-for-service model are common in European countries and the US and are increasingly sought by physicians and health care provider agencies. The most recent of many such programs in BC is the Longitudinal Family Physician Payment Model, which was introduced in 2023 to compensate family practitioners for time, patient interactions, and the number and complexity of patients in their practice. It has been taken up by over 800 new family practitioners and is now being emulated by several other provinces.

I also predicted that Canada would commit more national resources to health research. The Canadian Institutes of Health Research was created in 2000, with a budget about four times that of its predecessor, the Medical Research Council. New programs were created in support of health services

research and social, cultural, environmental, and population health research. Major new federal initiatives in support of research personnel (e.g., graduate students, research fellows, faculty) and infrastructure (e.g., the Canada Foundation for Innovation) allowed substantial rebuilding and expansion of Canada's health research endeavors. BC government support of health research was dramatically increased with the creation of the Michael Smith Foundation for Health Research (now Michael Smith Health Research BC) in 2001. Unfortunately, there has been relatively slow growth of federal health research funding since the major increases in the early 2000s. Canada's per-capita federal expenditures on health research are now a fraction of those in the US, and Canada ranks 10th among OECD countries in per-capita federal expenditures.[15]

Unanticipated developments

Opioid epidemic

Opioid use disorder is a long-standing social and medical issue that has reached epidemic proportions in recent years, affecting over 27 million people worldwide. The well-known adverse effects of opioid use, along with other controlled drugs, have been dramatically augmented in recent years by the advent of increasingly common fatalities from unregulated drugs. In BC, annual deaths have risen from 270 in 2012 to 2573 in 2023,[16] despite the declaration of a public health emergency in 2016. Efforts to understand and manage the problem of opioid use disorder and toxic drug deaths require ongoing research into its sociological, pharmacological, behavioral, regulatory/legal, and medical aspects. The four pillars of management (harm reduction, prevention, treatment, and enforcement) is a useful descriptive term, but there is currently no general agreement as to which option or combination of options to deploy in any given individual or community.

Medical assistance in dying

As recently as 2015, there was no legal way in Canada for a person with a terminal illness to obtain medical assistance in dying (MAID). In 2016, federal legislation authorized medically assisted death for adults with reasonable foreseeability of natural death who were suffering intolerably during the dying process. The reasonable foreseeability of natural death criterion was removed in 2021. Between 2016 and 2022, there were 44 958 medically assisted deaths in Canada, 4% of all deaths annually. As of April 2025, MAID cannot be specified in an advance directive (except in Quebec), and it is not available for persons whose sole medical condition is a mental illness or for minors (persons under 18 years), even if they are judged to be "mature."[17] Further legal and legislative changes seem likely in the near future.

Artificial intelligence

Artificial intelligence (AI)—that is, intelligence exhibited by machines, in particular computer systems—has been around since the 1950s, but its evolution has accelerated profoundly since about 2012, and it is being deployed across the breadth of human endeavors. The 2024 Nobel Prize in Physics was awarded jointly to John Hopfield and Canadian Geoffrey Hinton for their foundational discoveries and inventions that enable machine learning with artificial neural networks.

The application of AI is already accelerating the pace of medical research. The 2024 Nobel Prize in Chemistry was awarded in recognition of AI-enabled work on protein structure. Applications of AI to medical practice are already being anticipated by a Doctors of BC committee struck to study the potential of AI to serve the function of a medical scribe. The ethical dimensions of the availability of AI are immense and were stressed by Hinton in his Nobel address.

Summary

The delineation of the human genome and related advances in pharmacogenomics, genetic engineering, and transplantation are being rapidly translated into clinical practice, despite persisting ethical and legal issues that must be resolved.

Although Canada has, on a per-capita basis, substantially increased its complements of physicians in training and in practice and its investments in health research, it still lags behind many OECD countries. There have been many improvements in the organization of BC's health care system and in provincial and federal deployment of electronic health records, although interoperability remains problematic. Canadian medical education programs are evolving to better meet the needs of the population.

Canadian life expectancy at birth rose from 79 years in 2000 to 83 in 2024. Even though many nations face nonmedical determinants of health such as poverty, social disorganization, war, and environmental degradation, from which Canada has been relatively spared, global health data also reveal improved life expectancy at birth, rising from 66 in 1998 to 73 in 2020.

AI has burst into prominence, with its myriad potential benefits to medical research and practice and accompanying ethical and legal challenges.

It seems likely that medical progress will continue to accelerate, perhaps warranting a further update in 2050, although not by me. ■

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is anything to suggest past bacterial endocarditis, prophylaxis is still recommended.

- *S. aureus* is the most common cause of infections of various prostheses, including pacemakers, but it is not a major element of the mouth flora, nor a common agent of transient bacteremia with dental manipulation. In the case of an open abdominal wound with prolonged drainage, the wound is much more likely than an oral source to be the portal of entry.
- If the main concern is about reseeding a pacemaker with *S. aureus*, amoxicillin would not be expected to do very much, because most *S. aureus* is generally resistant to it.

We thank Dr Walter for the question and wish him excellent health!

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more than ever, we must stand together to strengthen our community, embrace new opportunities, and continue to advocate for the profession. As we mark this milestone, let's recommit to each other and our profession so we can build an even stronger health care system for future generations.

To all our physicians—past, present, and future—thank you for being part of this journey and, even more, for your unwavering commitment. Here's to the next 125 years of making a difference, one patient at a time. ■

—Charlene Lui, MD
Doctors of BC President

Images included on the cover, from left to right:

- Dr Steve Hardwicke with petitions signed by British Columbians protesting the government's actions to impose budget caps and limit doctors' bargaining rights, 1992.
- Academy of Medicine building, home of the BC Medical Association (BCMA) until 1985. Photo courtesy of the College of Physicians and Surgeons of BC.
- BCMA staff member Ms Tanyss Noftle with returned Medical Services Plan Payment Schedules, 1981.
- Members of the BCMA, 1906.
- Dr Ethlyn Trapp, the first female president of the BCMA, 1946.
- Drs Bill Jory and Bill Ibbott present Minister of Health Bob McClelland with a BCMA "Buckle Up & Live" bumper sticker, 1977.
- Indigenous artist sɬə́məxʷ (Rain Pierre) with his artwork, created as a beacon of safety for Indigenous patients and a symbol of culturally safe care that doctors can display in their offices, 2022.