SENATE SÉNAT
CANADA

CHALLENGE AHEAD

Integrating Robotics, Artificial Intelligence and 3D Printing Technologies into Canada's Healthcare Systems

Standing Senate Committee on
Social Affairs, Science and Technology

The Honourable Kelvin Kenneth Ogilvie, *Chair*

The Honourable Art Eggleton, P.C., *Deputy Chair*

October 2017

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ORDER OF REFERENCE

Extract from the *Journals of the Senate* of Tuesday, October 25, 2016:

The Honourable Senator Ogilvie moved, seconded by the Honourable Senator Eggleton, P.C.:

That the Standing Senate Committee on Social Affairs, Science and Technology be authorized to examine and report on the role of automation in the healthcare system, with a particular focus on robotics, artificial intelligence and 3D printing, in:

- Direct patient healthcare;
- Indirect patient healthcare; and,
- Home healthcare.

That the committee submit its final report no later than December 31, 2017, and that the committee retain all powers necessary to publicize its findings until 180 days after the tabling of the final report.

After debate,

The question being put on the motion, it was adopted.

Clerk of the Senate
Charles Robert

MEMBERS

The Honourable Senators who participated in this study:

Kelvin Kenneth Ogilvie, *Chair*
Art Eggleton, P.C., *Deputy Chair*
René Cormier
Tony Dean
Linda Frum
Nancy J. Hartling
Marie-Françoise Mégie
Richard Neufeld
Ratna Omidvar
Chantal Petitclerc
Nancy Greene Raine
Judith Seidman
Carolyn Stewart Olsen

Ex Officio Members:
The Honourable Senators:

Peter Harder, P.C. (or Diane Bellemare)
Larry W. Smith (or Yonah Martin)

Other senators who have participated from time to time in the study:

The Honourable Senators Beyak, Dagenais, Galvez, Gold, Griffin, MacDonald, McIntyre, McPhedran, Meredith, Poirier and Unger

Parliamentary Information and Research Service, Library of Parliament:

Sonya Norris and Dillan Theckedath, Analysts

Clerk of the Committee:

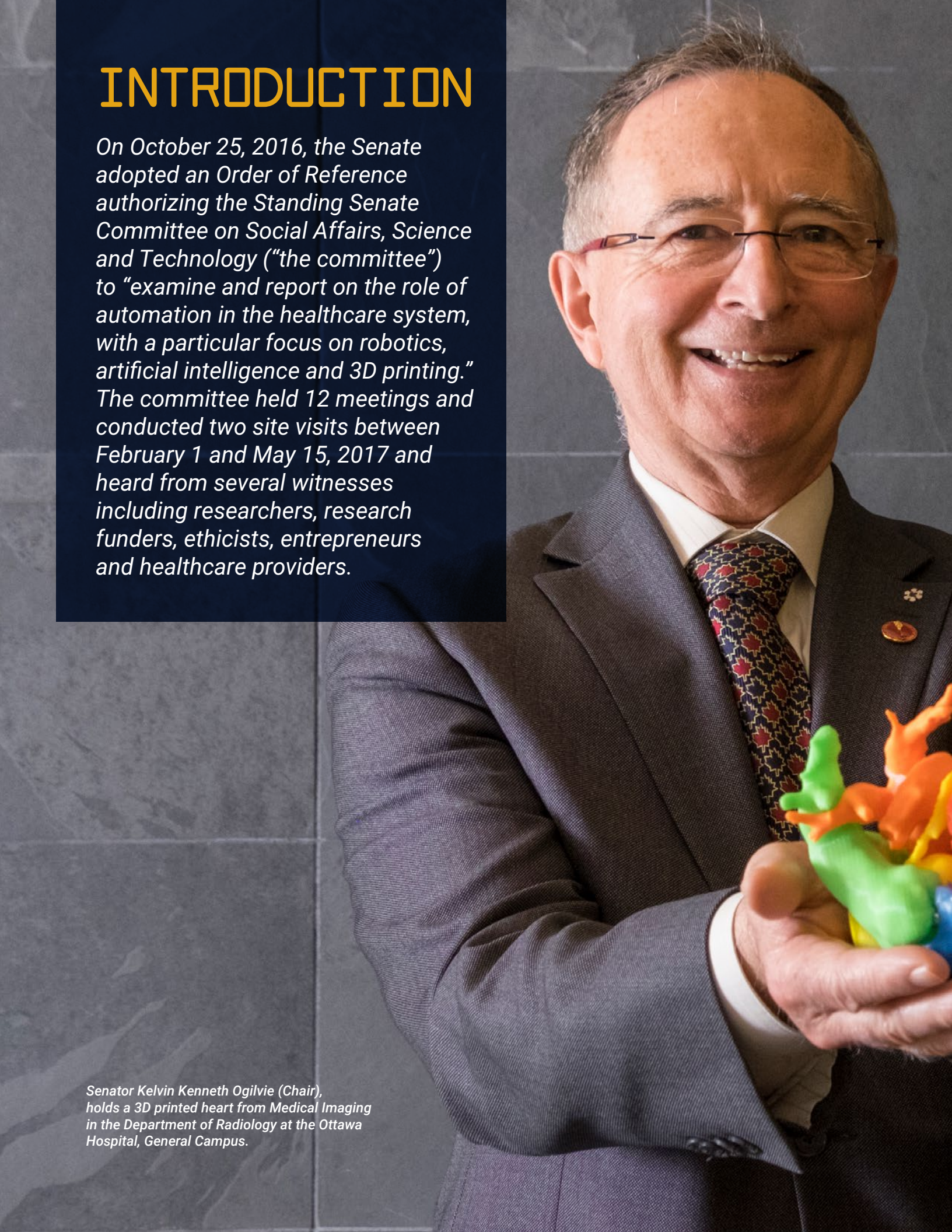
Shaila Anwar

Senate Committees Directorate:

Tracy Amendola, Administrative Assistant

INTRODUCTION

On October 25, 2016, the Senate adopted an Order of Reference authorizing the Standing Senate Committee on Social Affairs, Science and Technology ("the committee") to "examine and report on the role of automation in the healthcare system, with a particular focus on robotics, artificial intelligence and 3D printing." The committee held 12 meetings and conducted two site visits between February 1 and May 15, 2017 and heard from several witnesses including researchers, research funders, ethicists, entrepreneurs and healthcare providers.



Senator Kelvin Kenneth Ogilvie (Chair), holds a 3D printed heart from Medical Imaging in the Department of Radiology at the Ottawa Hospital, General Campus.

CONTEXT

The Canadian Institute for Health Information (CIHI) has reported that Canada's total annual health expenditure was forecast to reach $228 billion by 2016 with a growth rate of 2.7%.[1] Health expenditure includes both public and private funds, where public funds have made up around 70% of total health expenditure for many years.[2] The CIHI report also highlighted that the increase in health spending in recent years is hardly keeping pace with inflation and population growth, which leads to concerns about the sustainability of Canada's healthcare system.[3]

Over the course of many years, the Standing Senate Committee on Social Affairs, Science and Technology (this committee), has reported previously on health and healthcare in this country.

These reports have recently addressed:

- the need for Canada's healthcare systems to adapt and innovate in order to maintain viability;[4]
- the complexities of caring for individuals with chronic disease, which can in part be prevented by life-style choices;[5] and,
- the increasing needs of an aging population, particularly of those individuals with dementia.[6]

It was within the context of this committee's history of searching for solutions to help build a healthier Canada and the rise in recent years of automated innovations that can be applied to health and healthcare that the committee undertook its study on the role of automation in the healthcare system.

1 Canadian Institute for Health Information (CIHI), "**National Health Expenditure Trends, 1975-2016,**" 2016, p. 6.

2 Ibid., p.12.

3 Ibid., p.8.

4 Senate, Standing Committee on Social Affairs, Science and Technology, **Time for Transformative Change: A Review of the 2004 Health Accord**, Seventh Report, 1st Session, 41st Parliament, March 2012.

5 Senate, Standing Committee on Social Affairs, Science and Technology, **Obesity in Canada: A Whole-of-Society Approach for a Healthier Canada**, Second Report, 1st Session, 42nd Parliament, March 2016.

6 Senate, Standing Committee on Social Affairs, Science and Technology, **Dementia in Canada: A National Strategy for Dementia-friendly Communities**, Sixth Report, 1st Session, 42nd Parliament, November 2016.

BACKGROUND

The term "automation" refers to a broad range of technologies and can therefore involve a vast collection of innovations. In order to narrow the focus of the committee's study, the Order of Reference for a study on the role of automation in the healthcare system directed the committee to emphasize robotics, artificial intelligence (AI) and 3D printing. It was not the aim of the committee to delve too deeply into the science of these three areas, which can easily become more technical than is necessary to meet the goals of this study. Instead, witnesses provided a fundamental background on these technologies in order to allow members to appreciate the work and goals of the witnesses who testified before the committee.

ROBOTICS

Robotics involves the integration of information input with physical action. The information input can be in the form of AI and therefore robotics and AI frequently overlap. In healthcare, robots are used in laboratory and pharmacy automation, surgery or surgical assistance, exoskeletons, rehabilitation requiring physical therapy, assistance for the elderly or individuals with disabilities in performing daily activities of living and, assistance for individuals to prevent or treat cognitive decline.[7] Robotics technology can also incorporate telepresence innovation, therefore robotics becomes an important tool in providing healthcare in rural and remote locations.

ARTIFICIAL INTELLIGENCE

The term "artificial intelligence" was coined in 1956 and refers to the reproduction of human cognitive functions such as problem solving, reasoning, understanding, recognition, etc. by artificial means, specifically by computer. Applications of AI include game playing, speech recognition, understanding language, and heuristic classification (problem solving within expert systems).[8] While work in AI dates back to the 1960s, advances in computer capacity, the development of the personal computer and the Internet paved the way for a surge in interest in AI in the 1990s. The use of AI in medicine includes expert laboratory information systems that interpret diagnostic imaging, blood tests, etc., and deep learning systems that allow computers to learn from experience.

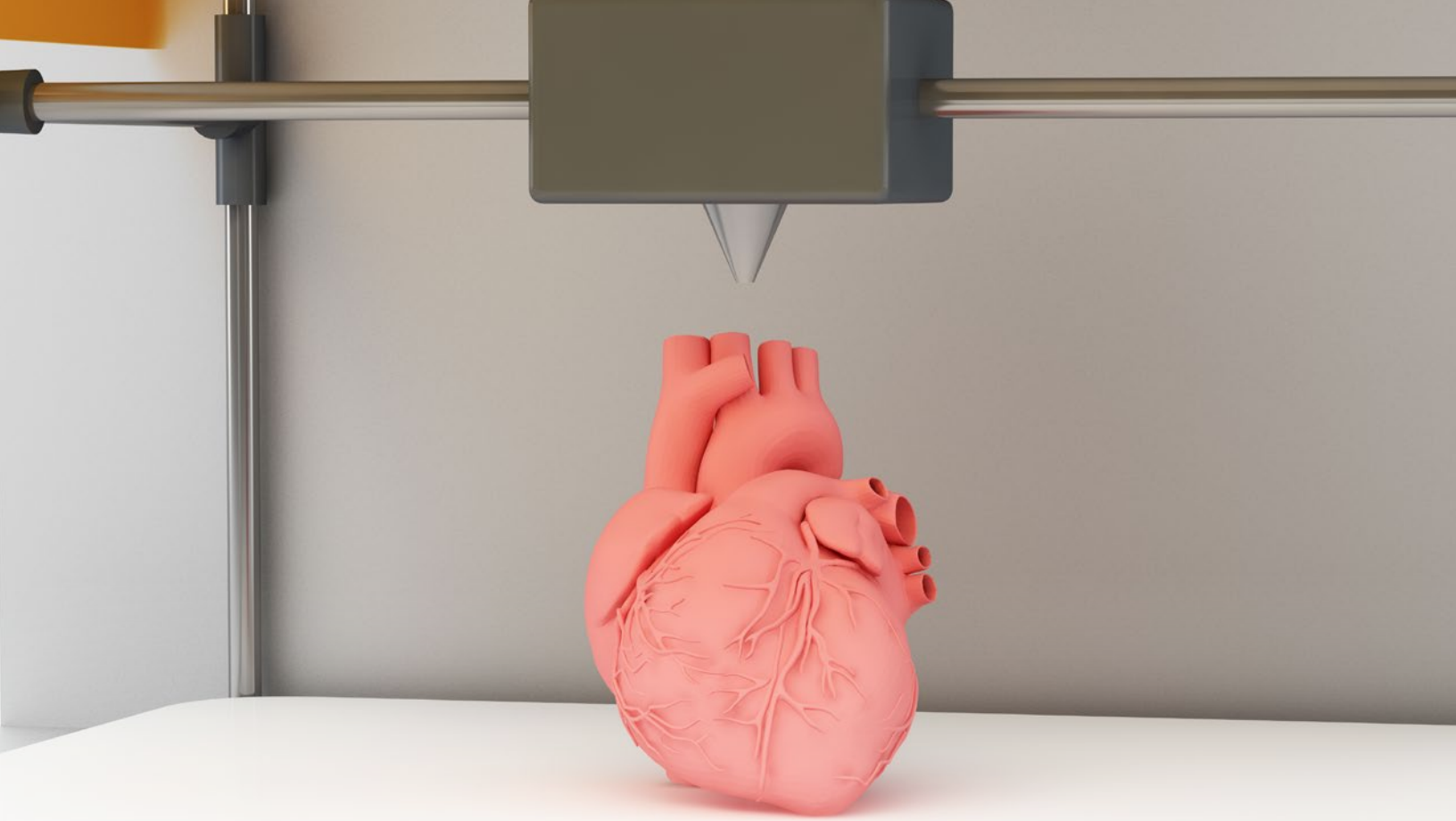
Artificial intelligence is only artificial intelligence until some critical mass understands how it works. Then it's just a computer program. It's nothing more.

- Daniel Silver, Director, Acadia Institute for Data Analytics, Acadia University

There is considerable overlap between robotics and AI. The degree of autonomy of a robot, that is the degree to which a robot requires human input, is directly related to its integration with AI.

7 Russell H. Taylor, "**A Perspective on Medical Robotics**," Proceedings of the Institute of Electrical and Electronic Engineers (IEEE), Vol. 94, No. 9, September 2006.

8 Jameela Ali Akrimi et al., "Review of Artificial Intelligence," International Journal of Science and Research, Vol. 2, issue 2, 2013, pp. 487–505.



3D PRINTING

3D printing involves producing several successive layers atop each other, ultimately producing a 3D object. Another term used is "additive manufacturing" which may be more accurate in describing the process. It uses a range of materials including various plastics and metals as well as biological material, namely cells. The technology for 3D printing has evolved since its invention in the 1980s to the point that it is now economical to use in small-scale production and for customized purposes.

Medical imaging has evolved from the creation of 2D images to 3D images. However, visualization of 3D images was previously limited to 2D flat screens and printouts. The advance of 3D imaging using Computerized Tomography (CT) and Magnetic Resonance Imaging (MRI) coupled with 3D printing technology now allows the production of a three dimensional object.

While the technology was initially used in engineering for the production of prototypes, there are several applications for 3D printing in medicine, including the fabrication of prototypes for surgical planning; designing implants; producing prosthetics and orthotics; regenerating tissues and organs; manufacturing surgical and medical tools; and, enhancing medical research, training and education.[9]

9 F. Rengier et al., "**3D printing based on imaging data: review of medical applications**," International Journal of Computer-Assisted Radiology and Surgery, Vol. 5, 2010, pp. 335–341.

THE ROLE OF THE FEDERAL GOVERNMENT

The provision of healthcare services is primarily the responsibility of the provinces and territories, although the federal government is responsible for the healthcare of certain population groups.[10] However, the federal government uses its criminal law power as the basis for legislating in a number of areas related to public health and safety.[11]

The *Food and Drugs Act* (the Act) is an example of the application of the federal criminal law power to ensure the safety of foods, drugs, medical devices and cosmetics.[12] Pursuant to the Act, the *Medical Devices Regulations* (the regulations) set out the requirements for approval and licensure for the sale of medical devices in Canada.[13] Under the Act and regulations, a medical device is an instrument, apparatus or contrivance, or any part of these, used in the diagnosis, treatment, or prevention of a disorder, or used to restore, modify or correct a body structure or its functioning, in humans. The regulations incorporate a risk-based framework and set out the assessment criteria for medical devices according to the level of invasiveness or potential hazard a device poses, where Class I devices pose minimal risk, such as thermometers, through to Class IV devices, such as cardiac pacemakers. Many of the innovations discussed during this study would be regulated as medical devices by Health Canada.

Under the regulations, Class I medical devices do not require Health Canada approval for a product licence, but an establishment licence is required for manufacturers, importers and distributors of Class I medical devices. Class II, III and IV medical devices do require the department's approval and a product licence in addition to an establishment licence similar to the requirement for Class I devices.

The federal spending power is also used in various areas related to health. The federal government uses the spending power to fund health research through the federal research granting agencies (the Canadian Institutes of Health Research (CIHR), the Natural Sciences and Engineering Research Council of Canada (NSERC) and the Social Sciences and Humanities Research Council (SSHRC)) as well as directly for research conducted at the National Research Council Canada.

10 The federal government is responsible for ensuring that healthcare is provided to the First Nations and Inuit population, Canadian Forces personnel, veterans, federal inmates and refugee claimants.

11 Martha Butler and Marlisa Tiedemann, **The Federal Role in Health and Health Care**, Publication no. 2011-91-E, Parliamentary Information and Research Services, Library of Parliament, Ottawa, 20 September 2013.

12 **Food and Drugs Act**, R.S.C., 1985, c. F-27.

13 **Medical Devices Regulations**, SOR/98-282

IMPORTANT PROGRESS FOR THE FUTURE OF HEALTHCARE

The committee invited two futurists to testify about the role of innovative technologies, specifically robotics, AI and 3D printing, in the future of healthcare. Bertalan Mesko, a medical futurist and Abishur Prakash, a geopolitical futurist from the Centre for Innovating the Future, spoke enthusiastically about the potential of these new approaches. Much of the testimony offered by subsequent witnesses reinforced the promising future outlined by the futurists.

A human-computer interaction design for a "digital twin" developed at the Multimedia Communications Research Lab (MCRLab) at the University of Ottawa.

Something is really changing in the Canadian scene, both in universities and in the makeup of the ecosystems of small and large companies that are investing in AI.

- Yoshua Bengio, Director, Montreal Institute for Learning Algorithms, Université de Montréal

FEDERAL INVESTMENT IN INNOVATIVE RESEARCH

Much of the innovation presented to this committee over the course of the study has benefited from public research funding in Canada, as well as private sector investment. In terms of federal funding, the committee was told that CIHR provides funding for the full range of health research as well as assistance in translating innovations into marketed products. Jane Aubin, Chief Scientific Officer, Research, Knowledge Translation and Ethics at CIHR, indicated that the agency has invested in each of the technologies described above, either directly to research investigators or indirectly through its support of, together with NSERC and SSHRC, the Networks of Centres of Excellence and the Canada Research Chair program, many of which were represented by witnesses throughout the study.

Bettina Hamelin, Vice President of Research Partnerships at NSERC, testified that NSERC funds basic research as well as innovative research partnerships. She outlined NSERC's support for research such as rehabilitative robotics for post-stroke and cerebral palsy therapy, AI use in "smart homes" that would allow aging in place, and 3D printing with bio-inks for tissue engineering. However, she pointed out that NSERC's budget has not increased in several years, despite the rising cost of research.

Finally, the committee heard from Roman Szumski and Robert Diraddo from the NRC who explained that the NRC's Industrial Research Assistance Program (IRAP) provides innovation support and funding services to help innovators market their products.

Several of the projects, investigators and organizations mentioned by these government agencies appeared before the committee to describe their exciting work. While several were supportive of the agencies' involvement in funding research in robotics, AI and 3D printing, they also raised concerns that the research funding agencies are not optimally positioned to work together. While the NCEs provide a good model of collaboration, members were told that improved and additional collaborative partnerships among the funding agencies could accelerate the pace of these innovations as well as encourage the sharing of ideas and advances.

It is important to support and grow such robotic innovation in Canada at the academic, industrial and clinical levels…We already have the people, the expertise and the drive needed to succeed in this robotics area.

- Goldie Nejat, Director, Institute for Robotics and Mechatronics, University of Toronto

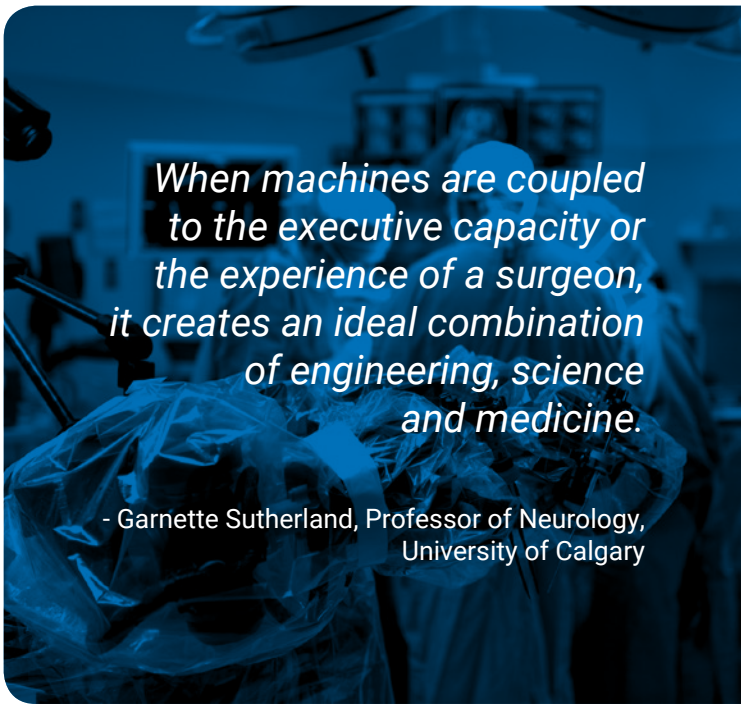
***Tangy**, one of Goldie Nejat's creations, is a socially assistive robot designed to facilitate recreational activities and promote social interaction among people with diminished cognitive abilities, such as individuals with dementia.*

ROBOTICS

Over the course of this study, committee members felt privileged to hear from some of Canada's leaders in innovative robotics research. Robotics research is an active pursuit across the country and the range of healthcare applications is broad. Goldie Nejat, Director of the Institute for Robotics and Mechatronics at the University of Toronto and a Canada Research Chair in Robotics for Society, discussed her work on assistive robots, an example of how some home care services can be provided by this innovative technology. She explained that robots can be used in the field of elder care, both in home and senior centres and residences. As a tool to promote aging in place, robots offer the means to reduce demands on formal and informal caregivers while also providing person-centred care that is designed for each user. Dr. Nejat described robots that can help individuals with their activities of daily living such as grooming, dressing and preparing meals and can be socially interactive for cognitive stimulation and companionship. The committee was told that this category of robot, personal assistive robots, will be in the private home setting in significant numbers within the next 5 to 10 years, as industry works to bring their cost down to $5,000 or less.

Dr. Sutherland performs neurosurgery using the NeuroArm.

Garnette Sutherland, a professor of neurosurgery at the University of Calgary, provided the committee with information about the role of robotics in direct patient care, namely in surgery. Dr. Sutherland explained that robotics, especially when coupled with imaging technology, is a powerful evolution for surgical techniques. He compared the importance of image-guided robotic surgery to the advances made in the late 1980s and early 1990s when many surgeries became less invasive with the development of the laparoscopic approach. Members were told that machine technology, using CT and MR images as well as GPS for target localization, is more precise than the human hand-eye coordination of the surgeon alone. While Dr. Sutherland described that he sits mere feet away from the image-guided robot that assists his neurosurgery, the committee also heard that this approach to robotic surgery differs very little from the telerobotic surgery which can enable surgical procedures to take place in rural and remote locations.



Other robotic technologies have moved beyond the research phase and have been approved for use in Canada. Ivar Mendez, Chair of the Department of Surgery at the University of Saskatchewan, described his work in telerobotics, also referred to as telepresence robotics and remote presence robotics. Dr. Mendez talked about the challenges involved in providing healthcare to Canada's rural and remote communities whose populations make up about 20% of the nation's total population. In particular, he described the high cost of transporting individuals from rural and remote locations to urban centres for examinations, tests, therapies and surgeries. Dr. Mendez has several remote

***Rosie** is a remote presence robotic system used by Ivar Mendez to provide patient care in rural and remote areas of Saskatchewan.*

presence robotics systems in place in various locations across Saskatchewan. These systems can be activated remotely by a physician. He explained that he can remotely drive the robot to check in at the nursing station and then to the patient's room to interview them and perform examinations with the assistance of a healthcare worker and by attaching peripheral devices to the robot such as ultrasound equipment or an electrocardiogram. This innovation allows for a remotely located specialist to examine and diagnose, and potentially treat, patients, which can save the cost and disruption of transporting them to urban centres. Dr. Mendez emphasized that this telepresence technology presents a powerful tool for improving access to healthcare in rural

Remote presence robot and Dr. Ivar Mendez. This technology is used to provide access to healthcare to northern communities in the Province of Saskatchewan.

and remote locations, but the committee notes that this application requires reliable high-speed broadband coverage in these areas.

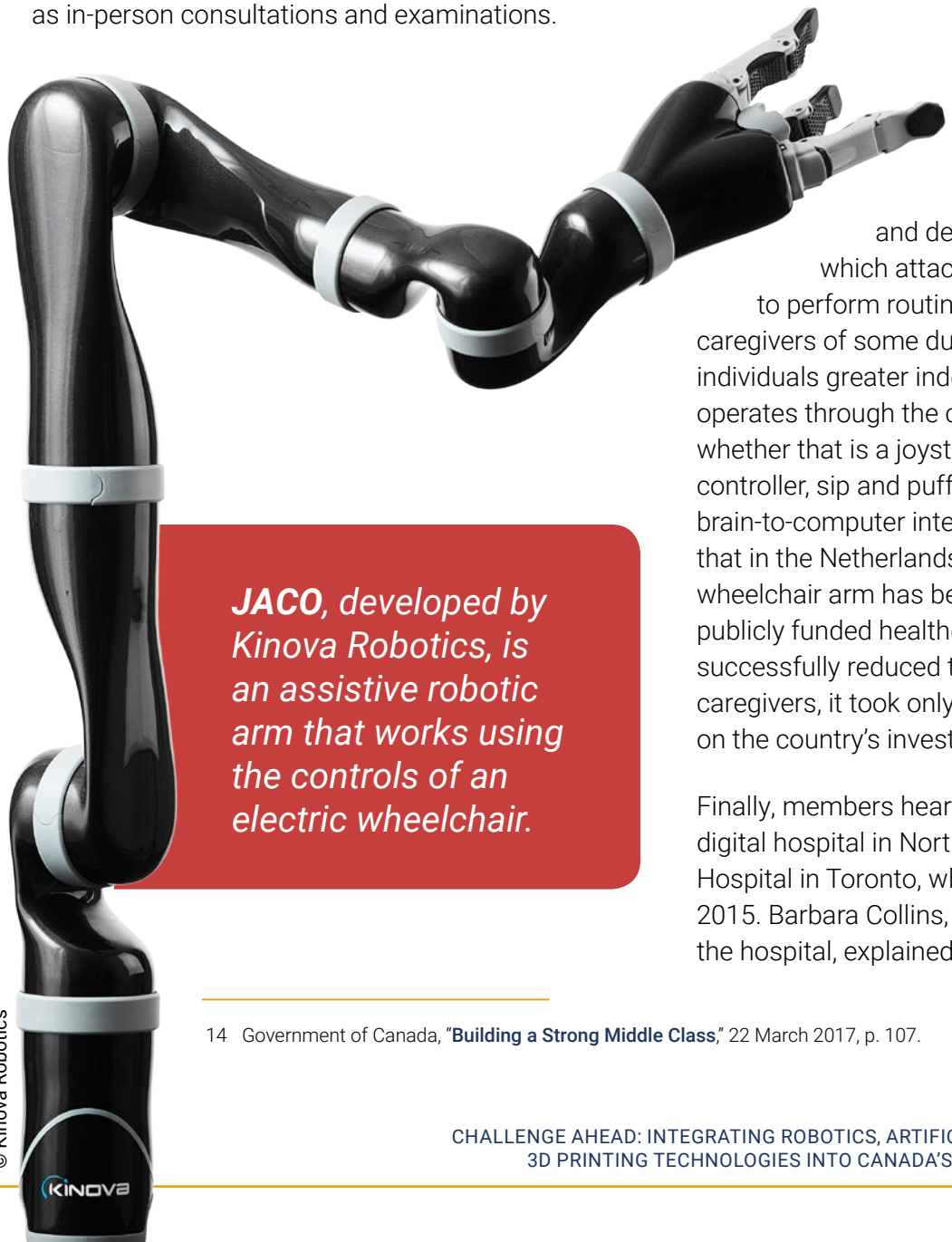
In this regard, the committee acknowledges the announcement made in the 2017 federal budget of $500 million to support the expansion of broadband networks in rural Canada.[14]

However, the committee is concerned that, because such service is rapidly becoming essential for healthcare access and delivery, unless progress is made quickly Canadians outside of major centres will continue to fall behind in access to healthcare delivery.

Finally, members were told that uptake of distance medicine by physicians could be encouraged by compensating it at the same rate as in-person consultations and examinations.

We have been using sophisticated remote presence robotic technology to see if it can be used as a tool to provide access to communities that have the least and need the most.

- Ivar Mendez, Chair of the Department of Surgery, University of Saskatchewan



© Kinova Robotics

***JACO**, developed by Kinova Robotics, is an assistive robotic arm that works using the controls of an electric wheelchair.*

Charles Deguire, the co-founder and President of Kinova Robotics, has designed and developed robotic arms which attach to electric wheelchairs to perform routine tasks thereby relieving caregivers of some duties and allowing individuals greater independence. This innovation operates through the controls of the wheelchair, whether that is a joystick, a chin, head or eye controller, sip and puff mechanism and even brain-to-computer interface. Mr. Deguire noted that in the Netherlands where Kinova's robotic wheelchair arm has been integrated into the publicly funded healthcare system and has successfully reduced the need for in-home caregivers, it took only two years to enjoy a return on the country's investment.

Finally, members heard about the first fully digital hospital in North America, Humber River Hospital in Toronto, which opened in October 2015. Barbara Collins, President and CEO of the hospital, explained that the hospital has

14 Government of Canada, "**Building a Strong Middle Class**," 22 March 2017, p. 107.

incorporated many robotic systems to carry out medication tasks. For example, some robots can prepare patient medications into dosing units and others can autonomously deliver the medications. Other robots have responsibilities for managing hospital supplies. Members were told that all the information is electronic at Humber River Hospital, which allows the hospital to have actionable data in all respects. This approach allows the hospital to work towards establishing a command centre where all operations will be consolidated and, using predictive analytics (AI), will optimize patient flow, minimize errors and optimize patient outcomes. Ms. Collins stated that the new digitized hospital has improved patient satisfaction by 20%, reduced hospital medication errors and reduced lengths of hospital stays.

Overall, the committee was told that robotics, despite being an expensive technology to initially develop, will bring about cost savings. Robotic surgery is more accurate and less invasive than traditional surgery, which leads to shorter hospital stays. Remote presence surgery and telerobotics reduce travel costs. Assistive robotics in home care can be less costly than hospital care. Witnesses also agreed that the cost of robotic technology has been declining in recent years and is expected to continue to decrease.

> *The hospital of the future is one where acute care and critical care are provided, but as much as possible we should keep people out of the hospital.*
>
> - Barbara Collins, President, Humber River Hospital

From left to right: Senators Art Eggleton (Deputy Chair), Marie-Françoise Mégie and Kelvin Kenneth Ogilvie (Chair) met with experts at the Ottawa Hospital, General Campus in May 2017.

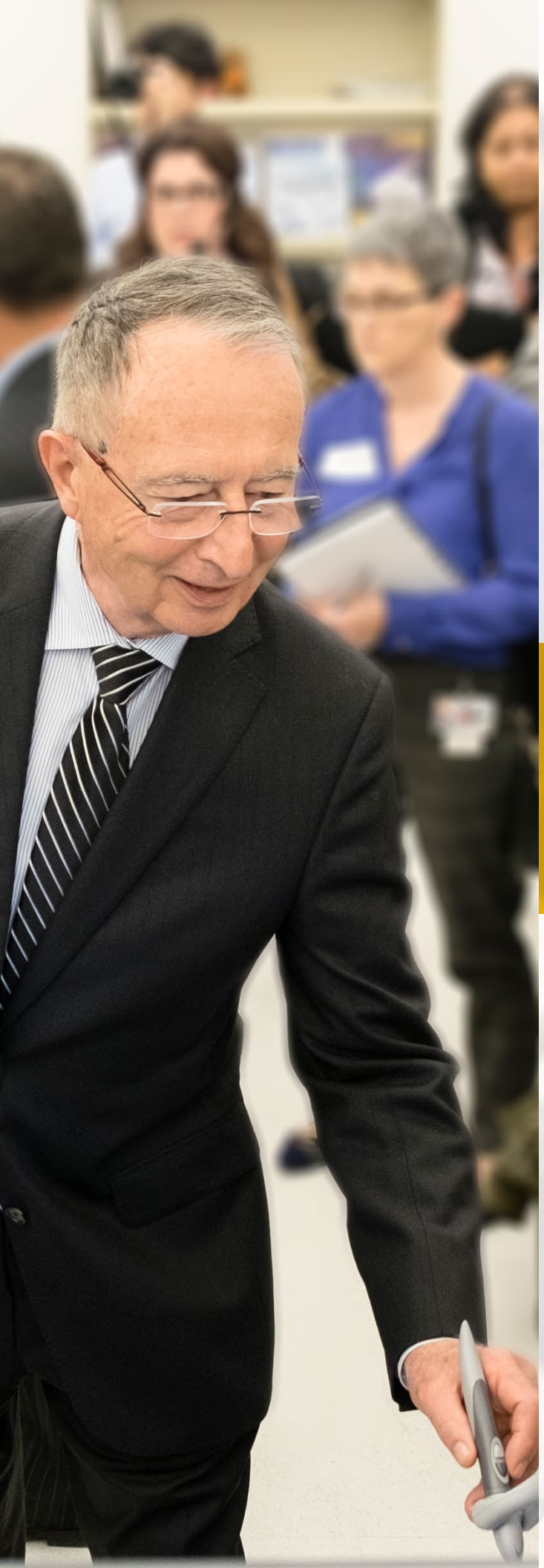
While robots can carry out physical actions, artificial intelligence is the brains behind the machine.

- Joelle Pineau, Associate Professor, Centre for Intelligent Machines, McGill University

ARTIFICIAL INTELLIGENCE

Artificial intelligence (AI), as the term suggests, aims to replicate human thinking, and much of the robotics field described above includes some level of AI. The primary type of AI research pursued in Canada over the years is known as neural networks, or deep learning. This aspect of AI was explained to members as simply applying the manner by which the human brain learns (through biological neural networks) to computer models (artificial neural networks). Deep learning therefore applies a mathematical, or digital, model that mimics the biological/physiological process of neurons (nerve cells) forming synapses (junctions between neurons) as the brain learns.

Committee members were told that AI is a very active area of research in Canada. In fact Subbarao Kambhampati of the Association for the Advancement of Artificial Intelligence stated that Canada continued to invest in AI research in its early years, specifically deep learning, after other countries had abandoned the field. The committee was told that Canada's continued support of basic research during the early years of AI, particularly at the Canadian Institute for Advanced Research (CIFAR), resulted in a high concentration of PhD candidates in the field and the creation of excellent AI research labs in Montréal and Toronto. This area of research has now surged in importance as it has become recognized that the development of AI requires mimicking brain function, the goal of deep



learning. While other countries have now gotten involved again, Canadian researchers are well advanced. As such, Dr. Kambhampati suggested, Canada deserves to reap the benefits of innovative applications of AI.

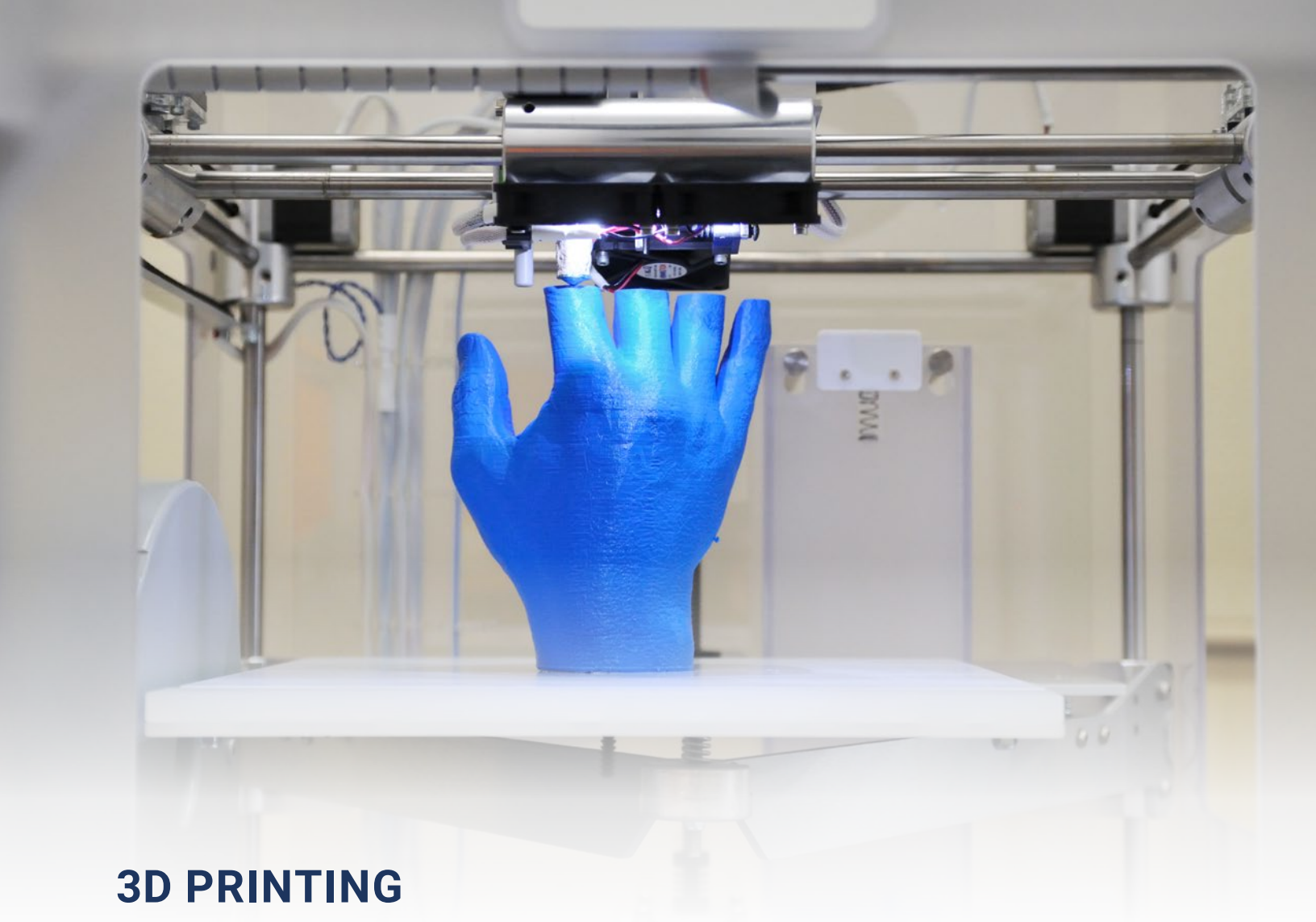
Committee members were told that deep learning will transform medicine. Daniel Silver, Director of the Institute for Data Analytics at Acadia University, explained that AI has, and will have, applications in: direct patient care to improve medical decision-making in diagnostics, prognosis, selecting treatment methods and in providing robotic surgeries and examinations; indirect patient care such as optimized hospital workflows and improved inventory management; and, in home care where wearable devices and sensors will be used to assess and predict patient needs.

Basically, when you learn something, what you have really learned is how to predict… Deep learning allows the computer to predict just as we predict.

- Alan Bernstein, President,
Canadian Institute for Advanced Research

Witnesses described promising AI research as being concentrated among three "AI hubs" in Montréal, Toronto and Edmonton. Joelle Pineau, a professor at the Centre for Intelligent Machine at McGill University, talked about "intelligent robots" in which AI is an essential component of the robot. She spoke about the potential of robots with an "AI brain" to interpret a complex set of data about a patient, determine an action that is required, and carry out that procedure on the patient. As an example she cited an artificial pancreas being developed at L'Institut de recherches cliniques de Montréal that is able to calculate insulin dosage based on real-time blood sugar levels and an individual's food intake, activity level and personal physiology.

Senator Ogilvie tests a biology-inspired, mechatronic and AI controlled pen at the BioIn Robotics Lab at the University of Ottawa.



3D PRINTING

3D printing, or additive manufacturing, has already been integrated as significant technology in the healthcare sector. Matt Ratto, an associate professor in the Faculty of Information at the University of Toronto, exhibited several examples of prosthetics and orthotics produced using additive manufacturing. The technology is low cost and can be carried out in remote locations with limited resources. He explained that these devices can be custom-produced for each user. The capacity for 3D printing to produce devices designed specifically for the user was suggested as the main reason why this technology is widely used in the manufacturing of custom hearing aids. Members were told that over 10 million hearing aids have been made using additive manufacturing.

Julielynn Wong, founder of the company 3D4MD, explained that the technology has several benefits. She indicated that the technology involved in manufacturing 3D printers has progressed to the point that tabletop printers are common and their cost has continued to decrease over the years to a range of $300 to $3000. As well, the cost of the plastic used as feedstock, or the printing material, is just pennies per gram. She argued that 3D printing is ideally suited to both on-demand and custom device production. Members were treated to a demonstration of the process as Dr. Wong used a tabletop printer to produce a custom fingersplint.

Konrad Walus, associate professor in the Department of Electrical and Computer Engineering at the University of British Columbia, provided insight into a different approach for 3D printing – tissue engineering with a view to regenerative medicine. In the case of this type of application, the "ink" is a biological material, namely cells. Dr. Walus explained that the printer would lay down layers of cells which would then be left to incubate and mature into a tissue. The cells in the tissue would communicate with each other rather than existing simply as a system of individual cells. In this way, a tissue could be regenerated using a patient's own cells that would not provoke an immune response and be rejected. Dr. Walus also described recent advances in this "bioprinting" technology which hopefully will lead to 3D printing of implants using an "ink" that closely resembles substances found in joints, such as the cartilage and meniscus of the knee joint. Another application of bioprinting that Dr. Walus described to the committee is in drug development. He indicated that tissue could be bioprinted and cultured in such a way as to express certain diseases. The engineered tissue would then be dosed with a new drug and the reaction monitored. He suggested that this testing model might speed up drug development, increase sensitivity of early testing and reduce the need for animal studies.

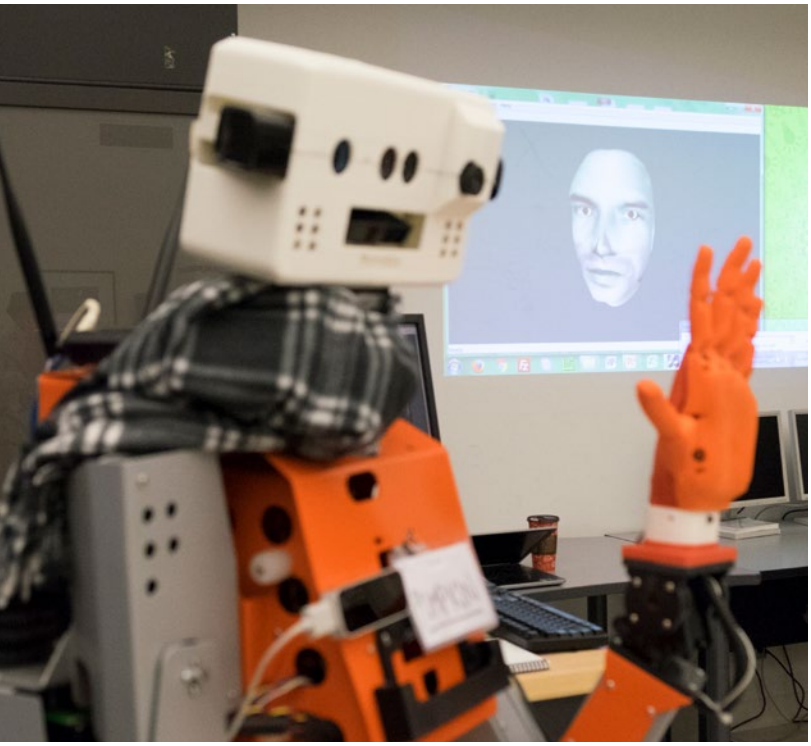
SITE VISITS TO THE UNIVERSITY OF OTTAWA AND THE GENERAL CAMPUS OF THE OTTAWA HOSPITAL

Members had the opportunity to visit a research lab and a hospital, to get first-hand exposure to these innovations. Members visited a multi-media communications lab where researchers at the University of Ottawa demonstrated virtual reality software that permits simulation of an injured person as a tool for both medical training and telemedicine. Researchers also demonstrated some biology inspired intelligent robots with expressive faces and a "skin" for robotic hands so that they can "feel" and respond to pressure and temperature. A visit to the General Campus of the Ottawa Hospital allowed members to see and examine a broad range of 3D printed objects and watch the creation of a 3D heart model on the hospital's on-site commercial sized 3D printer. Physicians described how this technology allows them to produce objects for planning surgeries and treatments, for implants, for explaining conditions to patients and for describing rare conditions to residents.

Senators René Cormier, Art Eggleton and Marie-Françoise Mégie interact with a "digital twin" developed at the Multimedia Communications Research Lab (MCRLab) at the University of Ottawa

A PEEK INTO THE FUTURE

As mentioned at the beginning of this section, the committee heard from two futurists, who helped to set the stage for the inspiring testimony that this committee was about to hear. However, they also provided some insight into healthcare of the future – should Canada take the steps to adapt to the new technologies. One prediction made by these witnesses was that luck will play less of a role in an individual's health and healthcare. Members were told that currently a person's health relies on the luck of the individual recognizing a symptom in time, getting to a physician, getting the correct



Multimedia Communications Research Lab (MCRLab) at the University of Ottawa.

diagnosis and the right treatment in a timely manner. In the future, these variables are likely to be minimized with wearable devices and in-home sensors for symptom recognition. The information collected would be relayed immediately to the healthcare provider who would use AI software to provide a diagnosis and suggests treatment options. These innovations would also permit a high degree of standardization for procedures, which would allow moving some procedures from hospitals to clinics that can be set up within the community, for example at shopping centres.

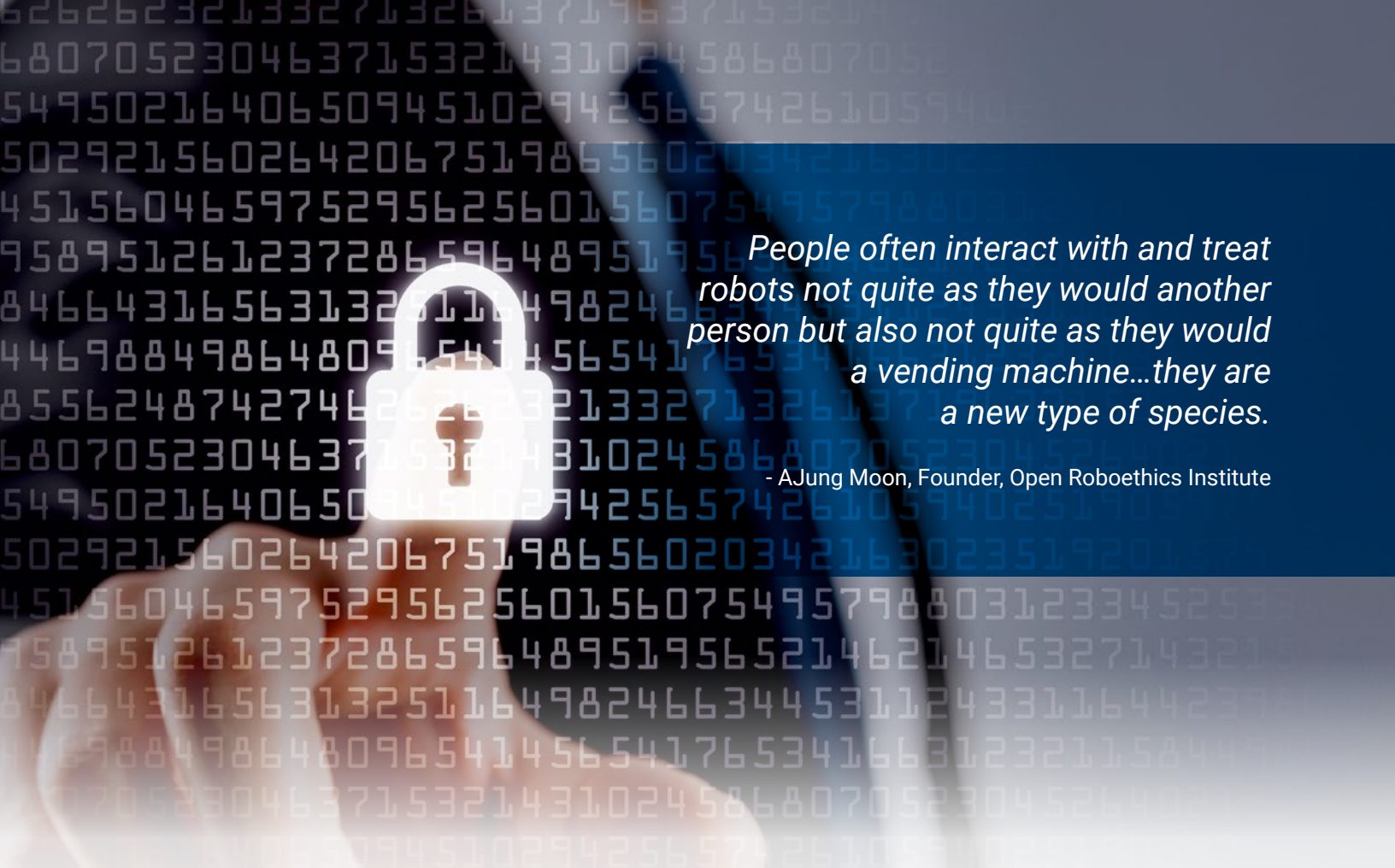
The committee was also told that the type of work done by Dr.Walus, bioprinting to produce living tissue, will progress to the point of more complex systems with a blood supply and finally to regenerated, fully functioning organs for transplantation. Finally, much further down the road, some experts see the emergence of fully autonomous robot surgeons.

Committee members were amazed at the innovations that were presented during the course of this study, humbled by the ingenuity on display and overwhelmed by the potential impact these disruptive innovations can have on the healthcare system. Of course, none of these advances will happen unless Canada can adapt to these innovative technologies and successfully integrate them into our healthcare systems.

Despite the enormous potential that rests with these technologies, members were struck by the need to be aware of some unintended consequences of integrating them into healthcare delivery. Concerns included ethical considerations, the impact on employment, difficulties in commercializing innovations, needed adjustments to training and education and updating the regulatory framework for medical devices. In order to be successful in integrating robotics, AI and 3D printing into healthcare delivery, Canada has to address the hurdles that lie in the way.

EYES WIDE OPEN

Despite the potential benefits expressed by many witnesses of robotics, AI and 3D printing in healthcare, a number of issues were raised as matters that must be kept in mind and integrated into plans as these innovations move forward.



People often interact with and treat robots not quite as they would another person but also not quite as they would a vending machine…they are a new type of species.

- AJung Moon, Founder, Open Roboethics Institute

ETHICAL, PRIVACY AND TRUST CONCERNS

The ethical issues associated with integrating these innovative technologies within the healthcare sector, as well as privacy issues and trust factors, were addressed by many of the experts who testified during the study.

Trust in the new technologies, by both healthcare workers and patients, is necessary if there is to be integration into the healthcare system. One hurdle to gaining trust is determining whether these new technologies will enhance healthcare, whether that is through improved safety of treatments, efficiency of services or by achieving cost savings. Another hurdle to winning trust is to ensure that people's privacy remains protected.

Members heard that the use of AI in diagnostics is at least as accurate, and often more accurate, than diagnoses by physician alone. For example, Alan Bernstein, President of the Canadian Institute for Advanced Research (CIFAR), presented evidence that AI outperforms healthcare specialists in the diagnosis and classification of skin and breast cancers as well as other conditions. Similarly, robotic-assisted surgeries were described as safer, less invasive and more accurate than traditional surgery. Further, members were told that strain and fatigue are reduced for surgeons in robot-assisted surgeries and in caregivers with respect to assistive robots in homecare.

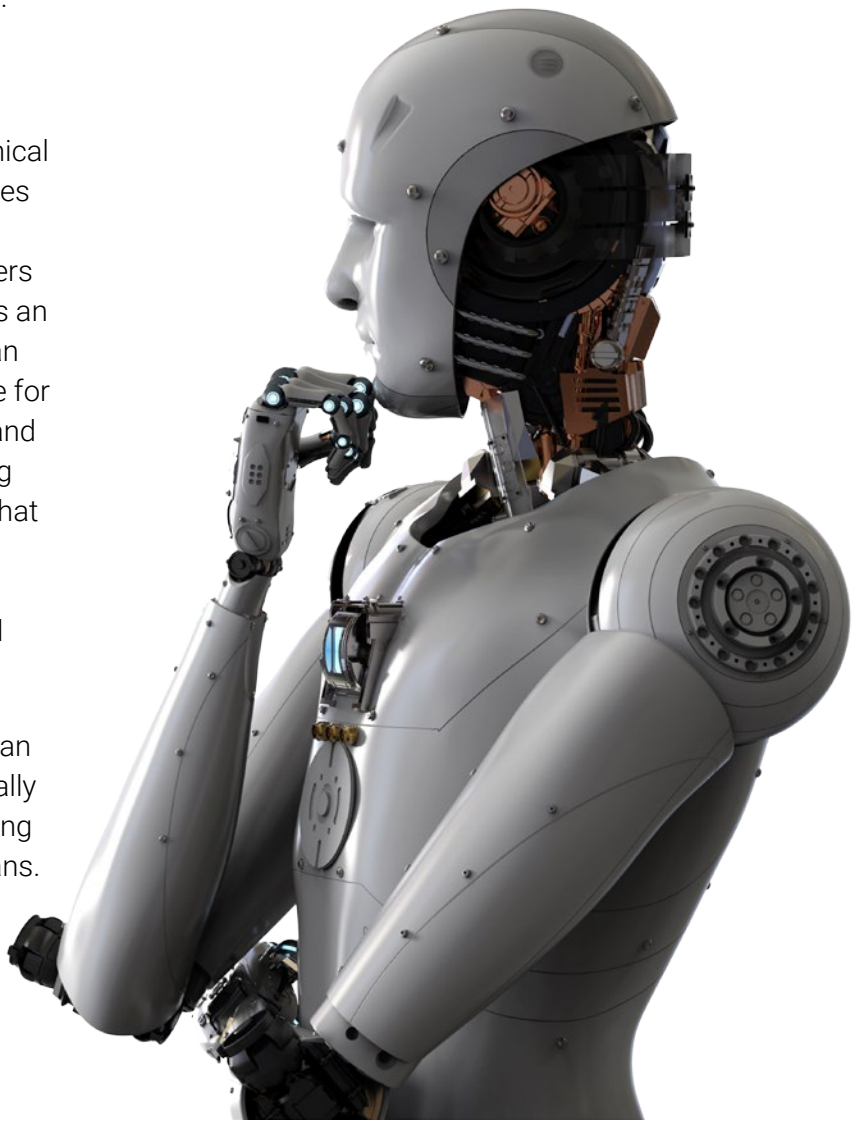
In terms of privacy, discussion focussed primarily on the use of AI, since it is this technology that depends on vast amounts of patient data. Assistive robots, in home care or elder care settings, might be constantly monitoring the individuals they have been programmed to assess, which can produce a tremendous amount of data. AJung Moon, founder of Open Roboethics Institute, who described robots as the physical embodiment of AI, suggested that the traditional concept of privacy may not be adequate within the context of these new technologies. Other witnesses pointed out that AI relies on patient data, the more the better. In this respect, witnesses spoke about the necessity to obtain permission to use patient data, encrypted and properly anonymized, for use in deep learning algorithms for a variety of applications.

Finally, deploying AI in an ethical manner that separates societal benefit from societal harm, was discussed. Members were told that the ethical issues surrounding these innovative technologies are being addressed proactively. For example, the Institute of Electrical and Electronic Engineers (IEEE), a professional organization that includes an international standards component, launched an initiative in 2016 called the IEEE Global Initiative for Ethical Considerations in Artificial Intelligence and Autonomous Systems with a view to developing ethical guidelines. While the committee heard that efforts to address ethical issues arising from these technologies are in their infancy, it is encouraged that the IEEE has implemented such a comprehensive program.

Autonomous robots, those that require no human input, were portrayed as being potentially ethically unacceptable as it could remove decision-making authority from patients as well as their physicians. For semi-autonomous robots, the ethical boundaries lay primarily in the amount and type of data included in the algorithm.

Consider an algorithm that can predict a heart patient's death. This type of prognosis can be offered by the tending specialist as well, and is not in itself unethical. However, the context of providing such a prediction must always be in a patient's interest, such as providing options for future care management.

The bottom line for many witnesses was that if healthcare workers and patients are presented with options that provide better outcomes, they will embrace them. Nevertheless, it is the responsibility of all stakeholders to keep these ethical concerns in mind as we move toward integrating the technologies into our healthcare services.



EFFECT ON JOBS

The committee was told that automation is projected to result in significant job losses in the coming years. While projections vary from country to country, members heard that 42% of all current Canadian jobs are at risk of being automated, or 7.5 million jobs. As such, the potential negative effect that these new technologies could have on the healthcare sector was frequently discussed throughout the study.

The committee heard from a few witnesses that job losses may result from these new innovations but most witnesses suggested that new jobs would be created. For example, Reinhard Lafrenz, Secretary General of euRobotics predicted that the new knowledge economy will create many new opportunities. Others witnesses suggested that existing jobs would be modified and enhanced to allow for the integration of automation. Some witnesses, for example Dr. Christopher Schlachta, Medical Director at the Canadian Surgical Technologies & Advanced Robotics (CSTAR), described these innovations as tools to enhance existing jobs.

However, the committee heard some words of caution from Yoshua Bengio, Director of the Montréal Institute for Learning Algorithms, that any new jobs created and any enhancements to existing positions, would demand a new skill set from employees. Similarly, members heard that there will be a need for enhanced focus on science, technology, engineering and math (STEM) in secondary and post-secondary education as well as re-training for the existing workforce. Futurists Bertalan Mesko and Abishur Prakash warned that if there is concern among people in the healthcare industry that these innovations could bring about job losses, there will be resistance to implement these technologies.

While the effect that robotics, AI and 3D printing will have on jobs cannot be accurately predicted at this point, it is clear that the issue must remain part of the discussion as Canada moves towards integrating these innovations into the healthcare sector.

These new technologies are only tools… They cannot be seen as replacements for the human touch that is needed in caregiving.

- Alex Mihailidis, Scientific Director, AGE-WELL, Network of Centres of Excellence

Getting a product through to market is a very complex and tortuous path.

- Roman Szumski, Vice President, National Research Council Canada

GETTING INNOVATIONS TO MARKET

The committee was told that there are a number of federally-funded programs that either directly or indirectly assist innovators to commercialize their products. CIHR devotes 23% of its $1 billion annual budget to priority-driven research in which the federal government identifies pressing health issues and provides funding to researchers who are conducting research in these specific areas. Some researchers who are funded under the priority-driven program are partnered with a relevant company. This partnership can help to move the innovations along to commercialization later on. CIHR, along with the other federal funding agencies NSERC and SSHRC, run various collaborative tri-council, or tri-agency, programs. Among the tri-agency programs are the Networks of Centres of Excellence (NCEs), which offer "programs that mobilize Canada's best research, development and entrepreneurial expertise and focus it on specific issues and strategic areas."[15] At least two of the NCEs are relevant to this study: the Aging Gracefully across Environments using Technology to Support Wellness, Engagement and Long Life (the AGE-WELL Network); and the Centre for Surgical Invention and Innovation (CSii) Network.

Alex Mihailidis, Scientific Director at AGE-WELL, described the NCE as bringing together over 140 industry, government, carers, end-users, academics and not-for-profit participants as well as 150 researchers from across Canada.

15 Government of Canada, **About the Networks of Centres of Excellence**.

AGE-WELL aims to improve the quality of life of older Canadians by developing technologies and services to promote independence and social interaction. This NCE was created in early 2016 with funding of $36.6 million over five years along with $22 million from partners. Members were told that AGE-WELL provides some support to its researchers to create start-up companies. To date the NCE has created two start-up companies and AGE-WELL expects that the royalty stream from all start-ups that it helps to create will allow the NCE to be self-sufficient after 10 years. However, Dr. Mihailidis noted that provincial healthcare systems require an overhaul in order to be more responsive and accepting of new technologies.

Mehran Anvari, Scientific Director at CSii, explained that the aim of CSii is to develop intelligent surgical robots that improve quality of, as well as access to, surgical and other interventional procedures. Dr. Anvari voiced frustration with respect to getting innovative products to market in Canada. He commended this country's support for research but stated that the support has to continue through to commercialization, otherwise there is no impact on patient care. He suggested that a major hurdle in getting products to market is the procurement process at the provincial level. Similarly, Charles Deguire, whose company Kinova has been licensed by Health Canada to sell his innovations, noted frustration about provincial procurement and getting his products listed in provincial health insurance plans, but also resistance to including them in private insurance plans. He revealed that 98% of Kinova's revenues come from outside of Canada and wondered why he has been able to market his company's robotic arms in other countries for several years while his own country has not welcomed the innovations.

Some witnesses suggested that there is little incentive for provincial healthcare systems to embrace these new technologies that can be costly and that have, so far, little history of safety and efficacy. The federal government, it was suggested, could play a role in encouraging provincial governments to integrate the new technologies into the publicly funded systems.

Over the course of the study, members heard from witnesses who had benefitted from NCE programs as well as the National Research Council's IRAP mentioned earlier. These witnesses identified strengths, weaknesses and gaps that need to be filled with respect to the commercialization of innovations in Canada. Konrad Walus praised IRAP and NSERC's programs as well as the partnerships with private companies, which together have facilitated access to design and prototyping services that are necessary components for researchers to take innovations to the start-up phase of commercialization. However, Garnette Sutherland was more cautious in describing Canada's innovation climate. He acknowledged that Canada invests quite a bit into basic and applied research but suggested funding agencies underestimate the cost of patent protection. He stated that translating research innovations into marketed products is a major handicap for Canada and that a lot of Canadian innovators take their products to the United States for marketing because Canadians don't tend to invest or take chances the way Americans do. Several witnesses suggested that Canada's research funding agencies should provide more support for commercialization of innovative developments in robotics, AI and 3D printing.

Finally, Mike Monteith of ThoughtWire, who appeared as a representative of the Council of Canadian Innovators, agreed that getting products to market in Canada is a major hurdle. He argued that access to capital is too difficult under the current business model which traditionally requires a two- to five- year business plan. He suggested that a plan that takes a longer view, perhaps 20 years, would be more appropriate for innovators of disruptive technologies, such as robotics and AI.

Mr. Monteith also emphasized that one of the problems faced by companies that attempt to scale up is frivolous lawsuits related to intellectual property rights, or patent infringement cases, brought by larger foreign companies that are intended to stymie competition. Mr. Monteith suggested that Canadian innovators would benefit from an intellectual property regime that supports them as they attempt to scale up their company and provides a system of pooled resources that would be used to defend innovators against spurious legal actions.

ADJUSTMENTS TO TRAINING AND EDUCATION

Several witnesses discussed the education and training needs associated with the introduction of these new technologies into the healthcare system. The committee was told that the era of passing through an entire career without the need for continuing education ended long ago and that healthcare providers are well aware of the need for keeping up-to-date with the steady advances in technologies. Members heard that these new technologies must be safely introduced into practice. For example, CSTAR's Kelman Centre for Advanced Learning provides simulation training to health professionals. In fact, it was suggested that the pace of change is so rapid now that the entire healthcare workforce may require regular retraining.

As mentioned earlier in this report regarding the concerns about job losses, some witnesses suggested a change in focus is required at the secondary and post-secondary education levels to increase attention to the STEM fields of study. Another perspective was offered by Yoshua Bengio. As discussed above, Dr. Bengio indicated that the new jobs created by these technologies will require different skill sets, most likely, than those of the people whose jobs have been replaced by automation. As such, he suggested that Canada's youth should be provided with an education that covers a broad range of skills so that they are better equipped to adjust to a change in workforce demands.

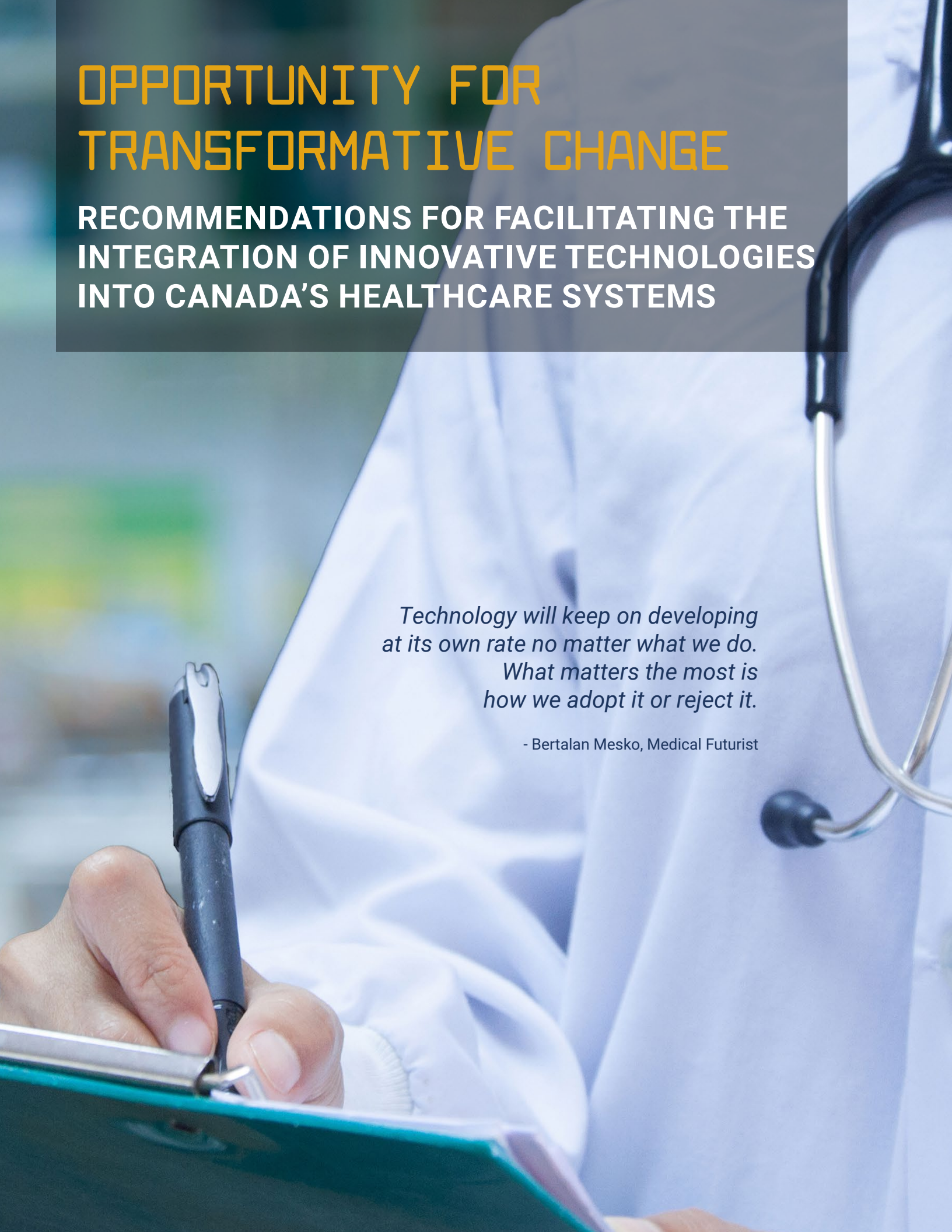
While it is clear that these innovations require that the workforce receive the proper education and training, it should also be emphasized that these new technologies provide exciting tools themselves for education and training. Members heard how 3D printing is becoming an important means not only for physicians and surgeons to plan treatment and surgeries and to better understand rare conditions, but also for these individuals to train residents and to explain treatment approaches to patients through the use of models that accurately reflect each patient's affected anatomy. Martin Ferguson-Pell, a professor in the Faculty of Rehabilitative Medicine at the University of Alberta, spoke of the potential for surgical planning in an augmented reality whereby a surgeon can manipulate 3D imaging data, for example MRI or CT scans, allowing the surgeon to enlarge the image as a hologram and to virtually get inside the anatomical structure to plan a surgery (a process called holoportation).

REGULATION OF INNOVATIVE MEDICAL DEVICES

Health Canada indicated that under the *Medical Devices Regulations* (the regulations) the department has approved and issued licences for innovations in all three categories; robotics, AI and 3D printing. It suggested that the current regulatory framework is appropriate for responding to evolving technologies. However, some witnesses suggested that some changes might help to make the regulatory framework more responsive. For example, under the regulations, in order to receive marketing approval from the department, the device sponsor must provide sufficient evidence from investigational studies of the device's safety and efficacy. Members were told that in the case of some of the innovative technologies, traditional randomized, controlled trials may not be the most appropriate approach and that the regulator should allow alternative approaches to determine safety and efficacy. Members were told that the European Parliament is currently working on a regulatory approach specifically for robotics.

OPPORTUNITY FOR TRANSFORMATIVE CHANGE

RECOMMENDATIONS FOR FACILITATING THE INTEGRATION OF INNOVATIVE TECHNOLOGIES INTO CANADA'S HEALTHCARE SYSTEMS



Technology will keep on developing at its own rate no matter what we do. What matters the most is how we adopt it or reject it.

- Bertalan Mesko, Medical Futurist

Witnesses informed the committee that federal investments have targeted AI research and the training of AI researchers. The federal budget, tabled in the House of Commons on March 22, 2017, stated that Canada must encourage innovation in order to remain competitive in the global economy.[16] Among the innovation-related measures introduced in the budget is the creation of a Pan-Canadian Artificial Intelligence Strategy by the Canadian Institute for Advanced Research (CIFAR) with a one-time allotment of $125 million. The strategy will be designed to attract and retain students, post-graduates and researchers primarily at newly created institutes within the three AI-hubs in Canada located in Montréal, Toronto and Edmonton, although funds will be available for other universities that would like to establish AI programs. The investment in a Pan-Canadian AI Strategy follows the September 2016 funding of three AI projects under the Canada First Research Excellence Fund totalling $213 million to three Montréal institutions (Université de Montréal, Polytechnique Montréal and HEC Montréal).[17]

The committee also learned of significant AI investment that will have an impact at the commercialization end of the innovation spectrum. Element AI, co-founded by Yoshua Bengio, is part research lab and part start-up incubator to facilitate the commercialization of products. Dr. Bengio noted that significant federal and provincial government investments have attracted further investments from large international companies including Google, Microsoft, Facebook and others. As he observed, this investment marks a change that signals companies coming to invest in Canada rather than the usual situation where Canadian start-ups have gone to the U.S. and Europe due to a lack of venture capital in Canada.

This engagement in AI research and commercialization also provides a solid foundation for robotics given the interconnectedness of these technologies, and the committee encourages the federal government to capitalize on current efforts. In this respect, the committee would like the federal government to build upon Canada's Innovation and Skills Plan and the Pan-Canadian Artificial Intelligence Strategy that were announced in Budget 2017 and take a leadership role in organizing a Canada-wide meeting of the minds. As has been done for various other issues, a "National Conference" would accomplish this goal. Specifically, a National Conference that involves officials from all levels of government and a broad range of stakeholders would serve to start and propel the conversation. It could in turn create the structure to identify the appropriate professionals to work together and develop the needed expert advisory capacity on a range of issues. In addition, the nature of disruptive technologies, as well as the rapid and dramatic advances expected, suggests that a prudent approach would include frequent consultation with stakeholders. Such an approach would be facilitated by on-going efforts involving a National Conference, a secretariat and expert working groups, as described next.

16 Government of Canada, "**Budget 2017: Building a Strong Middle Class**," 22 March 2017, page 17.

17 Government of Canada, **Canada First Research Excellence Fund – Competition Results**.

Therefore the committee recommends:

RECOMMENDATION 1

That the Government of Canada convene a National Conference on Robotics, Artificial Intelligence and 3D Printing in healthcare (National Conference). The National Conference should include a broad range of participants including:

- **federal, provincial, territorial and local government officials involved in industry, health and education, including indigenous representation, as well as,**
- **stakeholders with an interest in healthcare applications for robotics, artificial intelligence and 3D printing including, but not limited to, researchers, entrepreneurs, investors, health policymakers and health professionals.**

The purpose of the National Conference would be to have an open and frank discussion about innovative technologies and to propose ways to facilitate the successful integration of these technologies into Canada's healthcare systems. The committee feels that this initiative would take advantage of the dedication and enthusiasm that already exists in different areas of expertise and foster constructive debate. The committee heard from researchers and entrepreneurs that they thrive on challenges to solve problems that they face, but that changes are needed in business models and the way in which healthcare is delivered in order to see innovations through to market.

Therefore the committee recommends:

RECOMMENDATION 2

That the National Conference aim to capitalize on current efforts to integrate robotics, artificial intelligence and 3D printing into healthcare systems through open discussions and to identify relevant stakeholders to pursue areas of focus or concern that should be addressed in ongoing efforts through separate expert working groups. These groups should include:

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

RECOMMENDATION 3

That the role of each expert working group established by the National Conference be to develop its own strategic plan to encourage and facilitate the integration of innovative technologies into Canada's healthcare systems where appropriate after considering ethical, privacy, and safety issues. The number of working groups along with their mandates and memberships should be reviewed periodically.

RECOMMENDATION 4

That Health Canada, as regulator of these technologies, be represented on the ethics and regulatory oversight expert working groups to ensure that the work of international bodies responsible for exploring and advising on these and related issues be monitored and included in their deliberations.

A secretariat, comprised of the Chairs of each of the expert working groups, would allow for the coordination of plans and proposals of the various expert working groups. It would also provide a point of contact for the expert working groups and would report to the federal government.

The committee therefore recommends:

RECOMMENDATION 5

That a Secretariat be established that is made up of the Chairs of the expert working groups created by the National Conference. The Secretariat will:

- **coordinate the work of the expert working groups;**
- **collect reports produced by the expert working groups;**
- **report to the federal government on the progress of the working groups; and,**
- **provide any additional support required with respect to the work of the National Conference and the expert working groups.**

RECOMMENDATION 6

That the Government of Canada provide adequate funding for the ongoing efforts of the expert working groups and the Secretariat established pursuant to the National Conference.

RECOMMENDATION 7

That the Minister of Health, the Minister of Innovation, Science and Economic Development and the Minister of Employment, Workforce Development and Labour request regular progress reports on the work of the expert working groups established by the National Conference and, where necessary, discuss the conclusions and recommendations with their provincial and territorial counterparts.

RECOMMENDATION 8

That the Minister of Health request that the expert working group on regulatory oversight established by the National Conference address specifically, but not exclusively, whether any updates to the *Medical Devices Regulations* are required.

RECOMMENDATION 9

That the Minister of Innovation, Science and Economic Development request that the expert working group on commercialization established by the National Conference address specifically, but not exclusively, concerns related to intellectual property rights.

The committee heard frequently throughout the study that, to reach its potential, AI relies on large amounts of data, specifically high-quality digitized data. Members were reminded that Canada lags in its efforts to convert patient files to electronic formats including electronic health records (EHRs) and electronic medical records (EMRs). This committee has urged Canada Health Infoway (Infoway), which is responsible for accelerating the implementation of these digital systems, in previous reports to ensure that EHRs and EMRs are fully implemented across Canada.[18] Infoway's 2015-2016 Annual Report indicates that 73% of Canadian family physicians were using EMRs by 2015, an increase of 23% since 2006. As well, Infoway reports that the components of EHRs, which include diagnostic imaging and laboratory data, are approaching 100% coverage across Canada (with the exception of drug information systems which lag behind at 69%).[19] Members were told that complete digitized patient data over many years will provide the needed information for AI to provide predictive healthcare.

The committee therefore recommends:

RECOMMENDATION 10

That Health Canada, as a member of Canada Health Infoway's Board of Directors, request Infoway's participation in the National Conference in order to share with participants the progress that has been made in digitizing health data across Canada and to get their feedback on gaps that Infoway can help to address.

18 See Senate, Standing Committee on Social Affairs, Science and Technology, **Prescription Pharmaceuticals in Canada: Final Report - Appendices**, 18th Report, 2nd Session, 41st Parliament, March 2015, and Senate, Standing Committee on Social Affairs, Science and Technology, **Dementia in Canada: A National Strategy for Dementia-friendly Communities**, Sixth Report, 1st Session, 42nd Parliament, November 2016.

19 Canada Health Infoway, "**A Conversation about Digital Health – Annual Report 2015-2016**," July 2016.

Some witnesses expressed frustration regarding provincial procurement processes which have become a major hurdle when trying to get an innovation included on provincial lists of publicly funded services and products. Complementary to the work of the expert groups on commercialization and healthcare delivery renewal, the committee would like to see the participation of the Canadian Agency for Drugs and Technologies in Health (CADTH) in the National Conference on Robotics, Artificial Intelligence and 3D Printing. The CADTH, which issues listing recommendations to the provinces about approved drugs and devices based on cost-benefit analyses, could describe to stakeholders its role and activities related to robotics, AI and 3D printing.

The committee therefore recommends:

RECOMMENDATION 11

That Health Canada, as a member of the Canadian Agency for Drugs and Technologies in Health's Board of Directors, request its participation in the National Conference and in any of its relevant expert working groups.

In order to ensure that the integration of innovative technologies in healthcare continues to move forward, National Conferences should be held annually.

The committee therefore recommends:

RECOMMENDATION 12

That the Government of Canada convene annual National Conferences to assess overall integration of robotics, artificial intelligence and 3D printing into the healthcare systems across Canada and to identify and address new challenges as they emerge.

The committee commends the federal research funding agencies for their investment in robotics, artificial intelligence and 3D printing. However, it is concerned by testimony that the collaborative programs that involve the CIHR, NSERC and SSHRC could benefit from ongoing attention and analysis to identify and address research gaps.

The committee therefore recommends:

RECOMMENDATION 13

That the Presidents of the Canadian Institutes of Health Research, the Natural Sciences and Engineering Research Council of Canada and the Social Sciences and Humanities Research Council meet regularly to discuss mechanisms of collaboration that could be implemented to help accelerate research in robotics, artificial intelligence and 3D printing.

There are already many healthcare innovations in use in Canada, and many more prototypes and concepts in development. This observation guarantees that the traditional model of healthcare delivery will continue to be challenged by the disruptive force of new technologies and be driven by a population expecting access to the latest and most effective treatments.

However, the committee was told by entrepreneurs that innovation and uptake by the healthcare system could be accelerated in two ways. First, a national platform, a forum for discovery, where healthcare stakeholders as well as Canadian citizens in general could learn about new Canadian innovations and have an opportunity to speak to the creators. This forum would generate interest and demand. Second, the committee was told that innovative companies would respond to a challenge issued to resolve a stated problem. It was suggested that a healthcare challenge that affects all provinces and territories could change the future of every healthcare system in the country. Entrepreneurs suggested that it would be in the interest of the federal government to host an event that would address these two issues.

The committee therefore recommends:

RECOMMENDATION 14

That the Government of Canada host a Forum for Healthcare Discovery. The Forum would encourage interested innovators and entrepreneurs to:

- **share discoveries with the public and healthcare stakeholders; and,**
- **learn of additional healthcare challenges that could benefit from their ingenuity and dedication.**

CONCLUSION

The future of healthcare in Canada lies in our ability to innovate.

- Jane Aubin, Chief Scientific Officer,
Canadian Institutes of Health Research

[A]utomation, especially artificial intelligence, robotics and 3D printing, are essential in making healthcare sustainable.

- Bertalan Mesko, Medical Futurist

The innovative technologies addressed in this report are ones that offer, or have the potential to offer, person-centred healthcare. Whether that is a 3D model of a patient's diseased organ, an AI diagnosis based on a patient's specific symptoms and circumstances or a robotic arm that responds to a user's unique needs, these technologies will play an important role in the future of training and education, services to rural and remote regions, home care and personalized medicine.

The committee appreciates and respects the provincial/territorial jurisdiction over the delivery of healthcare services. However, the federal government has a responsibility to Canadians in terms of ensuring equitable access to healthcare. In this regard, it has an opportunity to take a leadership role to work with the provinces and territories to create the structure necessary to inform jurisdictions of the innovations available and the benefits they might bring to healthcare delivery while also highlighting the issues that require special attention.

These technologies are going to revolutionize the way Canadians live and specifically the way healthcare is delivered. Canada is already a leader in the theory and research underpinning these dramatic technologies and can become a leader in addressing concerns related to the ethics, employment, education and training, commercialization and regulatory updates. Canada can capitalize on the foresight of its investment in these research areas by mobilizing the talent and social structures necessary to return the benefits to our society.

APPENDIX 1:
LIST OF RECOMMENDATIONS

RECOMMENDATION 1

That the Government of Canada convene a National Conference on Robotics, Artificial Intelligence and 3D Printing in healthcare (National Conference). The National Conference should include a broad range of participants including:

- federal, provincial, territorial and local government officials involved in industry, health and education, including indigenous representation, as well as,
- stakeholders with an interest in healthcare applications for robotics, artificial intelligence and 3D printing including, but not limited to, researchers, entrepreneurs, investors, health policymakers and health professionals.

RECOMMENDATION 2

That the National Conference aim to capitalize on current efforts to integrate robotics, artificial intelligence and 3D printing into healthcare systems through open discussions and to identify relevant stakeholders to pursue areas of focus or concern that should be addressed in ongoing efforts through separate expert working groups. These groups should include:

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

RECOMMENDATION 3

That the role of each expert working group established by the National Conference be to develop its own strategic plan to encourage and facilitate the integration of innovative technologies into Canada's healthcare systems where appropriate after considering ethical, privacy, and safety issues. The number of working groups along with their mandates and memberships should be reviewed periodically.

RECOMMENDATION 4

That Health Canada, as regulator of these technologies, be represented on the ethics and regulatory oversight expert working groups to ensure that the work of international bodies responsible for exploring and advising on these and related issues be monitored and included in their deliberations.

RECOMMENDATION 5

That a Secretariat be established that is made up of the Chairs of the expert working groups created by the National Conference. The Secretariat will:

- coordinate the work of the expert working groups;
- collect reports produced by the expert working groups;
- report to the federal government on the progress of the working groups; and,
- provide any additional support required with respect to the work of the National Conference and the expert working groups.

RECOMMENDATION 6

That the Government of Canada provide adequate funding for the ongoing efforts of the expert working groups and the Secretariat established pursuant to the National Conference.

RECOMMENDATION 7

That the Minister of Health, the Minister of Innovation, Science and Economic Development and the Minister of Employment, Workforce Development and Labour request regular progress reports on the work of the expert working groups established by the National Conference and, where necessary, discuss the conclusions and recommendations with their provincial and territorial counterparts.

RECOMMENDATION 8

That the Minister of Health request that the expert working group on regulatory oversight established by the National Conference address specifically, but not exclusively, whether any updates to the Medical Devices Regulations are required.

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- share discoveries with the public and healthcare stakeholders; and,
- learn of additional healthcare challenges that could benefit from their ingenuity and dedication.

APPENDIX 2:
LIST OF WITNESSES

Wednesday, February 1, 2017	
Canadian Institutes of Health Research	Jane E. Aubin, Chief Scientific Officer and Vice President, Research, Knowledge Translation and Ethics
Natural Sciences and Engineering Research Council of Canada	Bettina Hamelin, Vice President, Research Partnerships
	Pamela Moss, Director, Manufacturing, Communications and Technologies (MCT), Research Partnerships
National Research Council Canada	Dr. Roman Szumski, Vice President, Life Sciences Robert Diraddo, Section Head Simulation & Digital Health, Medical Devices
Thursday, Feb 2, 2017	
Center for Innovating the Future	Abishur Prakash, Geopolitical Futurist
As an Individual	Bertalan Mesko, Medical Futurist
Wednesday, February 8, 2017	
As an Individual	Dr. Garnette Sutherland, Professor of Neurosurgery, University of Calgary
As an Individual	Goldie Nejat, Director of the Institute for Robotics and Mechatronics, Canada Research Chair in Robots for Society
Thursday, February 9, 2017	
As an Individual	Joelle Pineau, Associate Professor, Centre for Intelligent Machines, McGill University
As an Individual	Daniel L. Silver, Professor, Director, Acadia Institute for Data Analytics, Acadia University
Wednesday, March 8, 2017	
3D4MD	Dr. Julielynn Wong, Founder, Chairman and Chief Executive Officer
As an Individual	Matt Ratto, Associate Professor, Faculty of Information, University of Toronto
As an Individual	Konrad Walus, Associate Professor, Electrical and Computer Engineering, University of British Columbia

Thursday, March 9, 2017	
AGE-WELL Network of Centres of Excellence Inc.	Alex Mihailidis, Scientific Director and Associate Professor
Centre for Surgical Invention and Innovation	Dr. Mehran Anvari, Scientific Director
Wednesday, March 29, 2017	
Canadian Institute for Advanced Research (CIFAR)	Dr. Alan Bernstein, President and Chief Executive Officer
As an Individual	Dr. Christopher Schlachta, Medical Director, Canadian Surgical Technologies & Advanced Robotics (CSTAR)
Thursday, March 30, 2017	
SPARC (Partnership for Robotics in Europe)	Reinhard Lafrenz, Secretary General, euRobotics (by video conference)
Association for the Advancement of Artificial Intelligence (AAAI)	Subbarao Kambhampati, Professor, Arizona State University (by video conference)
Wednesday, May 3, 2017	
Montreal Institute for Learning Algorithms	Yoshua Bengio, Director, Professor, University of Montreal
As an Individual	Martin Ferguson-Pell, Professor, University of Alberta
Thursday, May 4, 2017	
Open Roboethics Institute	AJung Moon, Founder
Wednesday, May 10, 2017	
Council of Canadian Innovators	Mike Monteith, Representative, Co-Founder and CEO, Thoughtwire
Kinova Robotics	Charles Deguire, Co-Founder and President
Thursday, May 11, 2017	
Humber River Hospital	Barbara Collins, President and CEO
	Peter Bak, Chief Information Officer
As an Individual	Dr. Ivar Mendez, Chair of Surgery, University of Saskatchewan

APPENDIX 3:
BRIEFS

- AGE-WELL
- Canadian Institutes of Health Research (CIHR)
- Health Canada (written response)
- Martin Ferguson Pell

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