Horizon Scan of Diagnostic Technologies

Technology push or treatment pull?

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A well-functioning interface between the innovation and science systems is more necessary than ever to reap the economic and social benefits from public and private investments in research, ensure the vitality and quality of the science system, and improve public understanding and acceptance of science and technology and the importance of innovation.

Science, Technology and Innovation for the 21st Century
Meeting of the OECD Committee for Scientific and Technological Policy at Ministerial Level
29-30 January 2004

Preface

The Diagnostic Services Committee [DSC] was established in Ontario with the mandate to consider diagnostic technologies within the Ontario healthcare system, and provide advice to the Minster of Health and Long Term Care on diagnostic services planning.. As part of that process, the Committee mandated Tremblay Consulting to review current research and informed opinion from foresight studies and horizon scans with a focus on new and emerging diagnostic technologies.

This is one of five studies the DSC commissioned to provide an up-to-date picture of diagnostic services. The report identifies areas of technological development to the year 2020 and reports on trends that have the potential to influence diagnostic practices within the Ontario. This report, though, is not a prediction of the future.

The report's findings will help identify high-impact areas of new and emerging diagnostic technologies and trends of significance to help the Diagnostic Services Committee set priorities and chart a strategic direction for the role of diagnostic technologies in the province.

The evidence-base is as good as the work that is reported. Most of the research consulted consisted in:

- foresight studies (a systematic approach involving often very large numbers of experts in specific fields of interest, thinking about a particular technology over a period of time, in some cases up to a year or more) and

- technology horizon scans conducted, in the main, by governments, and national science and technology centres.

International and Canadian research was reviewed with a specific interest in finding studies from as many jurisdictions as possible.

Any new and emerging technologies likely to have an impact before 2011 are largely already in play, being at some point in a developmental cycle, or on their way to market entry and clinical use. The main areas we have considered are where existing or pre-launch technologies are likely to have impact on current thinking about the role of diagnostic technologies, their utility, application and cost. There are clearly defined developments in technologies within the next 5 years that are relevant to building a picture to inform decision-making on diagnostic technologies. The longer-term trends provide an opportunity to develop a strategic perspective.

The challenge is to understand how diagnostic technologies are changing and what that means. We are entering a revolutionary phase, which some dub "The Molecular Technology Era", to contrast it with the industrial era which has passed and the information era which is maturing.[1] This new era will focus technological development at the molecular scale through nanotechnology, biotechnology and materials science.

The study represents the situation as of August 2006.

Acknowledgements

The authors would like to thank the many people who provided information and insights, and helped guide our search. We would like to thank the Diagnostic Services Committee in particular for commissioning this work to inform their own deliberations on development of diagnostic technologies in healthcare systems.

As always, errors and omissions are the authors as are any interpretations of the potential implications that others may disagree with.

About the Authors

Tremblay Consulting

Established in 1997, Tremblay Consulting provides policy-oriented and strategic advice to senior leadership within the public and private sectors. Clients include governments, intergovernmental organisations (e.g. Council of Europe), pharmaceutical and medical device companies, information technology companies, retailers and organisations with a high-priority interest in health.

Michael Tremblay PhD

Mike has international experience in policy development, education, research and management. His work focuses on the European Union, (including UK, Spain, Hungary, Belgium, Malta, Netherlands, France), Canada and the US. Mike has enjoyed the confidence of elected members, senior government officers and executives. He specialises in emerging issues in health policy.

His recent work is on health system governance (such as the implementation of the LHINs in Ontario). He co-published on the regulatory impact in of the economic assessment of health technologies, in OECD countries, and developed policy to deal with the problem of international trade in counterfeit prescription medicines. He was expert advisor to the Council of Europe for Recommendation 2004(17) on new media and patients, and recently for regional e-health. He has also advised on innovation/research policy, higher education and training policy, e-health (electronic prescribing, digital interactive television, including setting up a digital interactive television channel to test its capabilities in healthcare), primary care reform and health professions regulation.

KTA Inc.

KTA is a consulting and research organization that provides high-level advisory services to government, business, and other public sector clients. Combining in-depth knowledge with our commitment to the highest calibre client service allows KTA to assist the organizations we work with in taking on their toughest challenges. KTA conducts its consulting through Practice Groups. These Practice Groups function with a combination of core KTA staff and associates. Our reputation for helping clients achieve organizational excellence rests on our ability to work through critical issues, and build strong partnerships between different organizations, levels of government, and the public and private sectors.

Suk-Hing Yiu PhD

Suk has experience in public policy research, analysis and development, particularly in the field of healthcare, science and technology. She spent most of her career with both the Canadian and the Ontario government, working in areas associated with scientific research, technology and sector development, as well as program reviews. She has helped established several key private and public sector partnerships in biotechnology and genomics research. She was one of the co-founders and the Interim Executive Director of the Ontario Genomics Institute. Her experience in technology assessment came from her association with the Innovation Foundation, a technology commercialization unit affiliated with the University of Toronto. When she was a

research scientist with the Canadian government in Ottawa, she specialized in imaging technology development and application.

Her past clients include the Ontario Ministry of Health and Long Term Care, the Ontario Ministry of Economic Development and Trade, the University Health Network, Toronto and Genome Canada. Her recent work examines the framework of governance and accountability associated with the Local Health Integration Networks of Ontario, and the barriers and incentives associated with public-private partnerships in R&D investments and technology commercialization. Through her past experience in the field of imaging technology, she has a keen interest in investigating the impacts of future diagnostic imaging technologies on human health and healthcare delivery.

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Report Summary

A single recommendation is proposed:

There should be a systematic approach to understanding and responding to change in diagnostic technologies.

The pace of technological development is rapid and in some respects accelerating, and across an increasing spectrum of technologies and clinical areas. This has the potential to swamp decision-making and priority setting bodies that may just not be able to process the necessary evidence quickly enough to meet the pace of change. This will undoubtedly require fresh insights into how we learn about, understand and make informed decisions about new technologies, how health technologies diffuse and the dynamic nature of health delivery systems themselves.

Detailed conclusions on technological change are organised around key areas of impact.

Implications for Patients and Patient Care

- It is anticipated that improved accessibility to diagnostic services will emerge as easier use of diagnostic technologies, changes in user-skills and interpretive expertise, enabled in part by networking diagnostic technologies, make it possible for diagnostic technologies to be more widely distributed geographically, as well into other institutions, most notably primary care.

- Patients should wait less, owing to fewer clinical encounters. In addition, it is anticipated that 'one-stop shops' (combining diagnosis and treatment) will become more commonplace.

- Improved diagnostic capabilities will make earlier diagnosis possible for patients, than at present; this will be partly driven by a preference to adopt a "best technology first" policy to improve productivity and clinical outcomes.

- The clinical preference toward minimally and non-invasive approaches will continue, with increasing emphasis on reducing patient discomfort arising from the features of the technology itself.

- Increasing personalisation of healthcare will continue with rising patient involvement in their care, involvement in decision-making and priority setting. As well, patient knowledge will be considerably higher than at present (arising from a variety of communication media including the internet, digital interactive television) and therefore much more salient around health technologies.

Implications for Patterns of Diagnostic Technology Use

- Diagnostic processes will be less focused on technologies themselves and more on the information (from digital scanning, diagnostic algorithms, and pattern recognition) that these technologies provide, as they become ubiquitous throughout the clinical treatment process, within care pathways and at point-of-care. Convergence between this "diagnostic information chain" and electronic health records (including patient-held information on smart cards as is already the case in many countries) will enable "information guided

healthcare" that occurs earlier than at present and uses 'smart' technologies with embedded artificial intelligence. This may be thought of as a paradigm shift from a service orientation on **diagnostic technology** with an emphasis on device capabilities to **diagnostic cognology** with an emphasis on information and analysis. This may have a major impact on current approaches to clinical decision-making as artificial intelligence and neural networks emerge as 'clinical assistants'.

- Diagnostic processes will be more widely distributed and networked, reflecting the shift toward prioritising the cost-benefit of the value of diagnostic information and outcomes over the cost-benefit of the device technologies themselves. This will disruptively enable diagnosis to take place in more non-traditional locations (compared to today), with increasing likelihood that clinical processes will be significantly reduced by eliminating service handoffs between diagnostic and therapeutic steps.

Areas of most potential for future innovation

- Potentially disruptive technological developments are anticipated in molecular medicine, with the development of 'molecular computers' to operate at the genetic and molecular levels to detect disease precursors.

- Nano-technology is expected to produce potentially disruptive developments within the next few years.

- Optical methods, including infra-red, spectroscopy and bioluminescence, are emerging diagnostic technology as they offer improved resolution over the limits of currently favoured technologies; with improved resolution comes the ability to diagnose earlier.

Emerging technologies that are already being prototyped exemplify potential clinical advantages and patient benefits. In many cases, the clinical applications are a technology transfer from other technologies or areas of scientific interest.

- Reduced costs: PETRRA is a PET with the capability of imaging 40 cm sections versus the current 16 cm. There is a claimed cost reduction (to perhaps half current levels). This is an example of technology transfer, in this case from the detection chambers used in particle physics.

- Smaller: A hand-held gamma camera is currently in development, with sub-millimetre resolution. This is an example of technology transfer from x-ray astronomy.

- Remote use: A portable hand-held robotic ultrasound device, which permits non-specialists to produce safe and reliable echographic diagnoses, an e-health diagnostic technology, utilised over a digital network.

- Non-invasive: Non-invasive diagnostic procedures are being developed to exploit digital modelling of data, e.g. virtual colonoscopy, a further development of computed tomography.

- Innovative: Novel developments are often triggered by capabilities in other fields, hence the emphasis on the examples of technology transfers and building interdisciplinary activities. The Electronic Nose is an example of olfactory sensors to detect odours linked to specific disease conditions, mimicking the detection abilities of dogs.

- Potentially disruptive: Molecular diagnostics is an area of considerable interest, with specific predictions of *ex vivo* and *in vivo* molecular computers specifically for diagnosis. In time, molecular computers will underpin 'smart' therapies, which involve embedding artificial intelligence within the diagnostic processes themselves. Bio-conjugated quantum dots, which are of considerable clinical interest as they can bond to specific biological molecules within cells, underpin the possibility of molecular and cellular imaging, to detect molecular signatures that are predictive of, for example, cancers. There is some speculation that neuro-imaging will develop to the point of imaging at the cellular level to create visual images of thoughts to aid diagnosis.

- Disruptive: Artificial intelligence [AI] is viewed favourably in many areas, with expectations that advances in predictive modelling of health/disease conditions will prove productive as there is a well-established research agenda on machine intelligence. The expanding role of AI will track the development of cognitive models of clinical reasoning and physical (deterministic) models of disease. AI and neural networks in healthcare are still at an early stage, but improved diagnostic outcomes are seen from efforts to link robotic vision with pattern recognition for computer assisted diagnosis.

- Patient focus: Future developments such as these are seen as precursors for 'individualised' medicine, based on developing causal and computational models of individual responses to treatment, rather than on epidemiological models, with their focus on populations.

Clinical areas most and least likely to benefit

- This emphasis on information-guided treatment will have an impact on areas of clinical activity that use diagnostic information. This will have both positive and negative implications, particularly for the demarcation of professional spheres of knowledge and responsibility. Information will flow more easily through health systems and be more readily available to all those who may require it when they need it, including the patient.

- Clinical activities, which may delay clinical processes, should become less so; indeed, later staged technologies that produce superior results are more likely to be used earlier as the 'best technologies first' approach offers improved system-level productivity gains and improved clinical outcomes.

- Increased computer power means that real-time (4D) processes will be the norm. The impact may be most pronounced in neuro-imaging with deep insights into the nature of the brain and brain dysfunction, and improved understanding of the determinants of mental ill-health.

- Molecules are becoming the focus of diagnostic interest with the ability to detect disease precursors earlier.

- Invasive diagnostic procedures will become less necessary as understanding of information gathered from molecular computers and image-based technologies produces comparable information.

- It has not been determined whether current concerns at rising whole population radiation doses (largely arising from increased use of CT) will cause further scientific or public concern and cause a shift toward technologies that do not use X-rays.

Implications for skill mix, clinical roles, service and system integration, innovation

- As diagnostic technology becomes easier to use and the results more accessible to non-specialists, the professional role demarcations between individuals who operate equipment, who interpret the results and who act on the information provided will become less significant. The effect will be to favour the end-user closest to the patient and who will combine all of these roles. There will be fewer hand-offs of clinical information between individual specialists or between service provider organisations. The effect is to integrate diagnosis with the treatment process. This will have the further effect of blurring what are at present defined boundaries between health professionals; it should be anticipated, for instance, that some skill and knowledge will shift from radiologists to physicians and surgeons. As newer technologies may require less specialist skills to operate, there will be challenges to the role of technicians who operate diagnostic technology.

- The potential of new diagnostic technology to end up in primary care and non-traditional settings is a possibility. The effect of technologies becoming easier to interpret and their use in remote locations define the e-health impact to decentralise some aspects of diagnostic roles to other levels of skills and knowledge. In particular, the ability of some diagnostic technologies to be used by lay individuals (e.g. in the home) with results being interpreted either locally through 'embedded intelligence' or remotely by a specialist in a central location, has the effect of altering the service delivery role of centralised diagnostic centres. Access to the expertise to interpret the results will become more important than physical access to the technology itself.

- A networked and distributed health service delivery system challenges the logic of skill aggregation that defines the hospital. However, this impact is not well understood. Generally, the trend of technologies as they mature is toward simplification and wide distribution with a corresponding impact on operator knowledge. healthcare has traditionally depended on centralised knowledge within hospitals, but greater technological diffusion in primary care and non-traditional settings has implications for this model.

- The innovative combination of diagnostic technologies with therapeutic interventions (e.g. interventional radiology, integrated therapy systems) offers the possibility of an increasing number of clinical work settings to be structured as "one-stop shops" for rapid diagnosis and treatment.

- New technologies do not always reduce costs; rather, they tend to offer greater treatment options and thus increase demand for service. However, emerging diagnostic technologies offer benefits to achieve productivity gains and better value for money as they simplify clinical work processes, yield improved patient outcomes, or enable one-stop diagnosis/treatment. The effect may be to provide improved sustainability in the face of rising demand by embedding diagnosis within a more integrated delivery system, through for example integrated care pathways.

Implications for the Assessment of Health Technologies

- Building foresight capabilities improves anticipatory capacity for decision- and policy-making as technological changes happen faster than our assessment systems can respond. Technology policy should focus on benefits realisation of future technology to realise value-for-money within technology planning and procurement.

- Assessing the impact of diagnostic technological change on society reflects changing society values, as new technologies offer new thinking on treatment, and identify new priorities for expenditure.

Strategic and Policy Implications for Ontario

- A more managed approach to technology introduction would permit earlier assessment of technologies to aid planning and priority-setting.

- Technology investment may act as an economic driver with benefits for the whole health system, an approach that other countries are exploring, with medical technologies having been identified in some jurisdictions as a priority. Having a well-developed and highly motivated research and development infrastructure in Canada presents Ontario with intriguing opportunities to explore how investing in new diagnostic technologies can benefit patients, as well as bring wider economic and productivity gains to the health system, with the potential to release resources for reinvestment in other areas of healthcare. Being an earlier adopter of new technologies has immediate implications for the scope of health technology assessment, with the possibility that outcomes and benefits can be realised sooner, while the disbenefits of immature or ineffective technologies can be identified sooner.

- There is potential disruption to the work of clinical professionals, and the blurring of roles between technologists, medical specialities and primary care providers and the potential to increasingly involve patients in their own care. This suggests that the educational needs of future health professionals will be affected.

- The decentralisation of the health system through the LHINs, highlights the potential impact of technological change on the mandate of LHINs when they consider diagnostic services. LHINs have the opportunity to leverage these potential technological changes to enable non-traditional, but potentially disruptive, forms of provision, including in patients' homes. The disintermediation of clinical processes, that move clinical service delivery to providers closer to patients, or the integration of clinical processes into one-stop patient encounters have important implications for service configuration.

- The role of health technology assessment is a major factor in making sense of the foresight and scan research. Ontario's existing commitment to world-class technology assessment of existing technology could be augmented by similar leadership in 'future-oriented technology assessment'.

- Public interest in health system priority setting is increasing with rising public understanding of healthcare technologies. Ontarians are interested in these technologies, and their impact on their potential future healthcare. The public will also be interested if these technologies lead to new integrated forms of provision in their homes.

1: The Present

Diagnosis has the potential to change a person's life; it is sometimes welcomed, but often feared.[2] Nevertheless, diagnosis coupled with improved clinical practice is a force for restoring health, or helping a person come to grips with long-term health conditions that will become their constant partner for the rest of their life.

Since the first 'modern' diagnostic technologies were developed in the 1970s and 1980s[3], advances in device technology have altered significantly the practical aspects of diagnosis, giving clinicians tools to visualise and probe the human condition at anatomical, functional and molecular levels. Patients have benefited from these technologies, as much as it has altered the practice of medicine. Three major sectors in Ontario (hospitals, independent health facilities and individual physician offices) offer diagnostic services.

The World Health Organization noted that 80% to 90% of diagnostic problems could generally be solved using "basic" X-ray and/or ultrasound examinations.[4] Based on 2003-2004 Ontario data, the Canadian Institute for Health Information (CIHI)) noted that Canadians seems to follow the same utilisation trend (80%). X-ray examination, including mammography, represented 63% of examinations, while the share of ultrasound was 16%. Computed tomography, nuclear medicine, MRI and coronary angiography accounted for respectively 11%, 7%, 3% and 1% of all medical imaging examinations.[5] Recent data for Ontario from the Ministry of Health and Long-Term Care [MOHTLC] indicate similar utilisation patterns.

The timing of this review paper could not be more appropriate either. Recent commentary has pointed to the need for improvements in the diagnostic evidence base:

"Evidence based diagnosis needs more primary evidence on diagnosis, more systematic reviews, and appropriate tools to translate the evidence into action."[6]

In the context of this review of the foresight literature, the need to couple these insights with rigorous anticipatory technology assessment are appropriate and consistent with current best practice guidance.

1.1: Why Does Diagnostic Technology Matter?

Diagnostic technologies matter in healthcare systems largely because diagnosis is the point at which clinical decision-making determines whether further clinical activity is needed. Treatment depends on a reliable diagnosis.

Given the impact diagnosis has on patients, a patient-centred definition can be helpful:[7]

> healthcare almost always begins with a diagnostic work-up: listening to the patient's complaint and history, examining the patient, and testing. It's the point when the physician determines, via some form of observation or measurement, that there's been a change in the patient's anatomy or physiology. And in many cases the news of a diagnosis from the physician changes the patient's life. The scope of diagnostic testing can be quite broad, including screening for disease or predisposition to disease in the general population or those assumed to be at low risk, tests applied to individuals who

are high risk or symptomatic to confirm a diagnosis, staging tests for when the diagnosis is known but the extent of disease is not, and monitoring of the disease course or effect of therapy.

Taking a "technologically neutral" [8] position on technology through a patient-centred definition emphasises a focus on the purpose of the technologies, the outcomes and the effects that flow from them. This ensures that considerations of possible future technology focus on the benefits of that technology, and not technical specification.

Diagnostic information enables clinicians to form judgements about the state of a person's health. The faster, better, sooner, more effectively diagnosis can be undertaken, the quicker people can know if there is a health problem, and the sooner resources can be appropriately organised for treatment. Waiting for a diagnosis is stressful for people and increases the burden of ill-health in society.

We are learning that before a person feels a symptom, and before an x-ray would show a shadow, or before a CT scan would reveal anything, cancer cells are present with a distinct molecular signature.[9] The challenge is to learn how to exploit these current and emerging diagnostic possibilities. The earlier that diagnosis can occur, particular at the molecular level, the more likely that a therapeutic intervention can begin at the same time, and importantly have the effectiveness of the therapy assessed virtually instantaneously.

For Ontario, there is no one, consistent picture of current and future diagnostic technology diffusion and distribution. This is despite diagnostic technologies being of great interest to various stakeholder groups, such as the Ministry of Health and Long Term Care, healthcare providers, LHINs, the Medical Advisory Committee, OHTAC, the Change Foundation, ICES and the Ministry of Research and Innovation in Ontario, plus CIHI, CADTH, Industry Canada, Health Canada, the National Research Council, and the academic and commercial research communities at the national level, and the Ontario public.

Ontario lacks a 'system' for diagnostic technologies.[10] Ontario, like many jurisdictions, conducts health technology assessments through OHTAC for market-ready technologies. These assessments are limited to what is currently available and health technology agencies cannot sensibly conduct evidence-*based* technology assessments of future technologies. However, an emerging field within health technology assessment [HTA], called *future-oriented technology assessment,* exists "to explore and assess the possible impact of technology on society in order to support policy making and aid the social debate by providing objective and non-partisan information."[11]

1.2: The Benefits Of Thinking About The Future

Most of the recent analyses on health and diagnostic technology in Ontario have been reactive, reflecting the focus on health technology assessment of already existing technologies, through MAS and OHTAC. This review offers the opportunity to establish the basis for a strategic direction to diagnostic technology development. Given rising consumer expectations, changing health priorities, and the strategic direction of the Ontario healthcare system itself, better knowledge is needed to structure appropriate technology acquisition and financing priorities.

The key benefit of thinking about the future lies in "looking ahead to avoid real dangers and to take advantage of opportunities, in the short-term and just as importantly, in the long-term, by developing the necessary thinking to anticipate change and plan for surprises."[12]

Horizon scanning adds to strategic planning capabilities in specific ways as described in the Table.[13] Three areas of impact are indicated.

TABLE 1: POTENTIAL BENEFITS OF ASSESSING FUTURE TECHNOLOGIES

Area of Interest	Area of Impact		
	Raising Knowledge	**Forming Attitudes & Opinions**	**Taking Action**
Science & Technology	Scientific Assessment Identifying and assessing technical options Understanding consequences of change in technology	Agenda-setting Raising salience of technologies Stimulating public and professional debate Offering 'visions' or 'scenarios'	Reframing Issues To further scrutinise a problem To provide new orientation to existing policies
Society	Social Mapping of potential impact Identifying stakeholder interests	Reflection amongst stakeholders Manage barriers and build bridges between groups	Decision-Making Intensify public and professional discussion
Public Policy	Analysis of potential impact on current policy and regulation Identify and assess implications of policy objectives	Restructuring debate Enhance scope of policies Enhance democratic legitimacy	Decision-making Filter alternatives out or in Focus on beneficial innovations

The possibility of releasing these sorts of benefits will be one way to underpin strategic reflection on future technologies and their impact on diagnostic services.

1.3: Canadian Experience

The Canadian experience with diagnostic technology foresight is largely limited to health technology assessments by OHTAC, Health Canada and the Canadian Agency for Drugs and Technologies in Health.

The tight time frame for existing assessments fits within a precise regulatory environment focused on emerging technologies which are either in use but not widely diffused (and therefore of potential, but undetermined, future use), or are focused on technologies likely to receive Health Canada approval within 6 to 18 months.[14] Foresight and horizon scan insights are not available to act as a decision-making lens in the manner of regulatory approval or an evidence-based review of an existing technology.

The difference between this sort of 'pre-regulatory' review and horizon scanning/foresight exercises is precisely in identifying technologies that have not yet been fully defined for clinical exploitation or diffusion, may only exist within experimental situations, or may exist only as scientific priorities for future technological exploitation. At an extreme end, some jurisdictions use foresight exercises to establish mission-oriented funding for basic as well as applied science priorities.

The Canadian federal government has undertaken specific foresight studies of imaging technologies, based on research dating to 1998. During 2002-2003, the federal government convened the interdepartmental Science and Technology Foresight Pilot Project under the auspices of the National Research Council to begin building "better capacity for anticipating or at least understanding the context for the kinds of surprises that our society may have to contend with sooner than many think".[15] Similar work, though, has not been replicated provincially, nor have other provinces coordinated any foresight activities or indeed formed common views on the potential benefits of future technology. However, unlike other jurisdictions contributing to this review, foresight capabilities have yet to be integrated into health policy and decision-making at the provincial or federal levels.

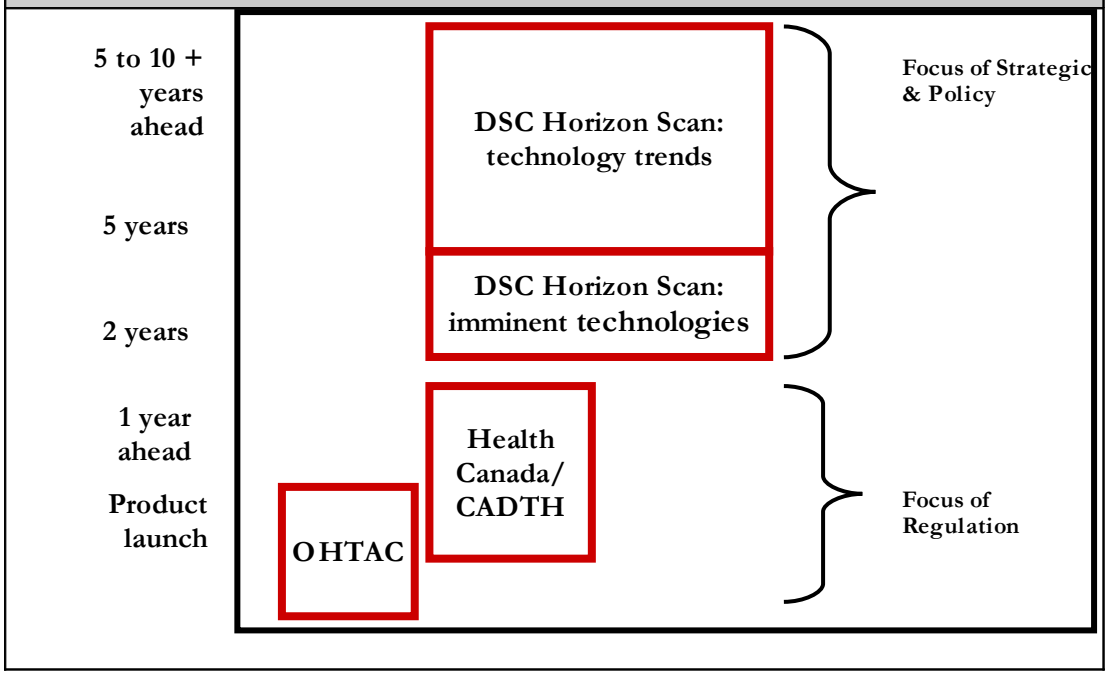
The National Research Council [NRC] maintains a research perspective on medical technology, but responsibility for adoption and reimbursement of diagnostic technologies lies with the provinces. There is also foresight capacity within the Office of the Science Advisor in the Privy Council Office of the federal government.

The Canadian Agency for Drugs and Technologies in Health conducts technology assessments focused on technologies within 6 months of approval by Health Canada or within 18 months of launch onto the market.[16] Health technology agencies in Canada do not conduct technology foresight studies, but rather conduct horizon scans within a 2-year window to assess new and emerging technologies; this time frame is consistent with Health Canada's. Alberta has determined that for their own planning purposes the Health Canada horizon is sufficient. [17]

The risk of adopting shorter time frames lies in assuming that current health technology assessment horizons are adequate for provincial policy making, resource and priority planning. It also means that the impact of potential new technologies may not be sufficiently well-understood across the dimensions identified in Table 1: within science, at a social level and within public policy. Adopting longer time frames would put provincial health system planning within what many OECD countries consider as good practice for system planning.

This report picking up where these bodies leave off, using time frames from foresight studies and exploratory literature, probes the future to the year 2020.

DIAGRAM 1: HORIZON SCANNING TIME FRAMES[18]



1.4: International Experience

Most OECD countries have established foresight programmes with many further prioritising an understanding of future health technologies. In most cases, studies are conducted by governments, scientific societies or research agencies.

Foresight studies are increasingly accepted as a way to condition the policy-making environment to be receptive to anticipated changes in technologies usually between 5 and 15 years ahead. There is a link between national technology policy and foresight – and the absence of the former usually indicates that the latter does not exist. Increasingly, though, technology foresight is being linked to identifying areas for national technology investment and priority-setting within a globally competitive environment. Japan is noteworthy for ongoing reviews of its scientific and technological priorities through Delphi and foresight studies with specific comparisons to research and development priorities in the United States [US] and the European Union [EU].

The political context of foresight work is also important, with new priorities being put in place following the major terrorist events in the US of September 2001 to identify security technologies; security is a major feature of very recent technology foresight studies and absent from earlier ones. As diseases have re-emerged, foresight exercises have added the need to consider how health systems can respond to future but changeable health scenarios. Climate change modelling is a specific example where foresight studies are identifying potential future pressures on health systems. The collapse of the internet bubble brought a needed rethinking on technology investment, while convergence of nanotechnology, biology and information technologies has emerged as an important new focus.[19]

The European Commission funds extensive foresight studies to inform policy. It has also established the Institute for Prospective Technological Studies for this purpose.

The RAND Corporation has conducted major foresight work. Microsoft Research in the UK completed a significant and much reported study; it focused in part on computational medicine. The US-based Institute for the Future produced a report specifically dealing with future diagnostic technologies.

This report reviewed many foresight studies, including:

- the Institute for the Future and the RAND Corporation in the US,
- the Santa Anna IT Research Institute in Sweden,
- the European Commission's Expert Group on Foresight, and their Institute for Prospective Technological Studies based in Spain,
- the Institute of Physics, the Office of Science and Technology, Microsoft Research (Cambridge) and the Department of Trade and Industry in the UK,
- the National Institute of Science and Technology Policy, Ministry of Education, Culture, Sports, Science and Technology, Japan,
- the Ministry of Science, Israel,
- the Fraunhoffer Institut Systemtechnik und Innovationsforschung, Germany, and
- Industry Canada and the National Research Council, in Canada.

The majority of these studies were conducted since 2002. In addition, a review of the clinical literature produced an extensive list of recent scientific peer-reviewed papers with a 'future' orientation on new and emerging diagnostic technologies.

1.5: Factors Influencing Change In Diagnostic Technologies

Changes in diagnostic technologies arise from a confluence of factors and not all forces of change are evidence-based.

In general, clinicians have specific criteria for adoption of any resulting technological change:

- scientific evidence that the additional information adds clinical value or produces diagnostically accurate information,[20]
- methods work in day-to-day clinical practice.[21]

Health system managers would add:

- availability of money to purchase the technology and put it into use.[22]

In addition, other factors with impact on the patient are driving developments and include:

- sensibilities amongst clinicians to reduce the discomfort and pain associated with much diagnostic practices and therefore to prefer technologies that are pain-free (non- or minimally-invasive as much as possible),
- rapid interpretation so that time required to perform the examination decreases reducing stress on patients, or specific requirements which can be discomforting (such as sitting still for long periods of time, of holding one's breath),
- patient throughput increases so patient waiting is reduced,[23]
- increasing the speed of the technology, making it smaller and more portable, permitting moving the technology to the patient rather than the other way around,
- in the case of necessarily invasive technologies, the administration of sedatives or analgesics should become an avoidable development. [24]

Key factors drive trends in changes in technologies themselves:

- increasing the power of the technology to be more accurate, precise, sensitive, or targeting to specific areas of interest,
- making technologies simpler, easier to use, safer, requiring less technical expertise to use and interpret results including being less operator-dependent,
- making technology "smart".

Increasingly, too, technologies are being transferred from space science, e.g. radio-astronomy, where sophisticated imaging technologies are finding application in medicine. The European Organisation for Nuclear Research, CERN, is the world's largest particle physics laboratory, based in Switzerland, and it has identified healthcare as a natural domain for technology transfer of its work. This reflects core priorities at CERN, including the technically demanding nature of diagnostics, and increasingly sophistication of clinical therapeutics. CERN is already involved in technology transfer around PET, SPECT, and CT as well as the use of GRID computing[25] to create a distributed database of mammograms.[26] Imaging and photonic advances are similarly defined work programmes with the NRC in Canada.

The computer and its capabilities are constantly pushing forward technological changes, with diagnostic technologies being one area which is seen as changing as a result. The **Towards 2020 Science** foresight study from Microsoft Research[27] focused on advances in computing, which when applied to diagnostic technologies point to key features of emerging next generation technologies.

In general, software has moved from requiring highly specialised knowledge of how computers work to the situation today where most people use software with little if any idea how the software works. Future developments of software point to increasing "machine intelligence" from the use of artificial intelligence and neural networks, and evolving capabilities designed to duplicate how the brains work in machines. As well, the next generation diagnostic technologies

are likely to exploit advances in robot vision and pattern recognition for image processing. This appears to be a particularly potent force for technological change.

And of course the twins of innovation and serendipity will continue to surprise us.

2: Developments in Specific Diagnostic Technologies

2.1: Taxonomy Of Current Diagnostic Technologies

The nature of technological change for a variety of diagnostic technologies were identified in the foresight and horizon scan documents. These various studies used different time frames for their projected changes, but in general, all tend to be near term, over the next 5 years, to 2012 or so, with most terminating their future perspective between 2015 and 2020. The Japanese foresight studies go as far as 2030-35.

The developments reported in the following sections reflect the scope of the material reviewed, and should not be considered a complete review of all possible diagnostic technological developments, presenting a snap-shot of what, in the opinion of the experts who authored the studies, is thought likely. The opinions on the impact on patient care of these technologies similarly reflect the views of those participating in the foresight studies and should be further assessed for specific technologies of interest. This does provide a starting point, though.

The table identifies the current preferred technologies for a variety of health conditions in Ontario.

TABLE 2: MAJOR DISEASES/MEDICAL CONDITIONS AND THEIR CURRENT ASSOCIATED MAJOR DIAGNOSTIC TECHNOLOGIES IN ONTARIO

Diagnostic Technology	Cardio-vascular, Thorax & Abdomen	Chronic Obstructive Pulmonary Diseases	Neurology, Head & Neck[6]	Musculo-skeletal, Joints & Chronic Pains	Cancer[1]
X-Ray[2]	■	■	■	■	■
Ultrasound	■	■	■	■	■
Nuclear Medicine[3]	■	■	■	■	■
Computed Tomography	■	■	■	■	
Nuclear Magnetic Resonance Imaging	■	■	■	■	
Endoscopy	■	■			■
PET/CT	■				■
Electrodiagnostics[4]	■	■	■		
Others[5]		■	■		

[1] Cancer: lung, colorectal, breast, prostate, vascular

[2] X-Ray: includes basic x-ray, fluoroscopy, bone mineral density, mammography and angiography

[3] Nuclear Medicine: includes scintimammography, positron emission tomography, single photon emission, computed tomography, myocardial perfusion scintigraphy, radiopharmaceutical tracers

[4] Electrodiagnostics: includes electrocardiography, electroencephalography, electromyography, polysomnography

[5] Others: spirometry, ophthalmoscopy

[6] Neurology: top 10 disorders: addiction, anxiety disorders, obesity, chronic pain, depressive disorders, sleep disorders, hearing loss, attention disorders, Alzheimer's, vision-related.

Based on the information in this table, a taxonomy of current diagnostic technologies was developed, reflecting the categories of use and reimbursement for diagnostic technology in Ontario. This taxonomy is subsequently revised at the end of the report reflecting the study findings to take account of future technological development.

TABLE 3: MEDICAL DIAGNOSTIC TECHNOLOGIES IN REGULAR USE IN ONTARIO[28]

Imaging				Electro-mechanical
Echocardiography (3D, 4D) Echoencephalo-graphy Elastography High Frequency Doppler Ultrasound Mammary Ultrasonography Microbubbles Enhanced	Diffusion MRI Echo-Planar Imaging Functional MRI Magneto-encephalography MR Angiography MR Cholangio-Pancreatography MR Cine Imaging (Wall Motion Studies) MR Spectroscopy	Angiography Arthrography DEXA (bone density) Diagnostic X-Rays Fluoroscopy Multiple Gated Acquisition (MUGA) Scan Myocardial Perfusion Scintigraphy Neuroradiography Scintimammography	Hybrid PET/CT Multi-slice CT Positron-Emission Computed Tomography (PET) Single-Photon Emission-computed Tomography (SPECT) X-Ray Computed Tomography	Audiometry Electrocardiography Electroencephalo-graphy Electromyography Plethysmography Polysomnography (sleep studies) Spirometry (pulmonary function)
Ultrasound	**Magnetic Resonance Imaging**	**Radiography**	**Tomography & Nuclear Medicine**	**Other**

Of considerable current interest is the development of hybrid technologies, combining the features of MRI with CT or CT with PET, or other combinations of technologies. The NRC sees the market for conventional radiography and fluoroscopy, single-slice CT scanners and hybrid gamma cameras configured for SPECT and PET scans to decline in sales growth (hence clinical interest and use). Areas for growth are seen as 'anything digital' such as digital radiography units, multi-slice CT, open and ultra-high-field MRI, multi-modal CT/PET and portable ultrasound. [29]

Many of the technological developments envisioned in the literature will encounter 'hard' barriers imposed by physical limits, and this will have a future impact on the role these technologies will play or such limits may encourage new avenues of discovery and innovation. Some examples of barriers include:

- PET resolution is limited by the physical behaviour of positron decay, amongst other factors.[30]

- PET and SPECT are tomographic, and, while they permit relatively precise location of areas of interest, have resolutions exceeded by new optical methods such as bioluminescence with finer, but still limited, resolution.

- CT acquisition scanning speeds are now faster than the rate at which a contrast medium travels through the vascular system.[31]

- SPECT imaging is limited by the weakening of low energy photons by body tissues, which "introduces an error in relating the intensity of probe signal to the concentration of the tracer".[32]

Greater use of CT is also pushing a limit to what is the acceptable total amount of radiation in clinical settings. Hart and Wall[33] determined that in the UK, the rise in CT popularity had increased total x-ray dose; CT's accounted for 7% of all radiological examinations, but contributed 47% of total x-ray doses from all medical examinations.[34] Concerns like this have driven the development of various standards including most recently an EU directive on electromagnetic fields.[35] The impact of rising population radiation dosage is an issue that will need understanding within a whole-system approach to diagnostics.

2.2: Ultrasound

Ultrasound imaging (sonography) is the most widely-used technology in the world today[36], and is a non-invasive, alternative technology to confirm diagnostic resulted obtained from X-ray and physical examinations, for instance in confirming mammography results.

Experts identified that future advancement of ultrasound technologies will be in the areas of higher image resolution, more sensitive detection of high frequency sound waves and equipment miniaturization.[37] In the shorter term, changes will focus on development and use of more novel contrast agents, more specialised instrumentation such as more complex transducers, and four-dimensional ultrasound and the use of technologies with greater sensitivity.[38]

With ultrasound, the key features of the first two generations in its development have largely comprised technical advances in the original invention, while a third generation reflects the use microprocessors.

TABLE 4: GENERATIONAL MODEL OF ULTRASOUND[39]

Generation	Brief Description
I	Handheld with a 2D probe taking as many 2D images as are necessary to cover the area of interest
II	Mechanically driven transducer acquire a series of 2D planes producing a 3D image
III	2D phased array transducer acquires a volume of data producing 4D images

The potential use of contrast agents in ultrasound to enhance image detections provides a means to differentiate benign from malignant tissues. The use of more sensitive techniques, such as colour Doppler sonography[40] and microbubbles greatly enhance productivity in the anatomic and physiologic assessment of organs and disease conditions. The rapid development of these new sonographic techniques is expected to enlarge the scope of clinical applications in a variety of disorders.[41] Furthermore, recent research in using Endoscopic ultrasound to locate cancerous

tissues along the gastrointestinal tract may lead to an expanded use of ultrasound in cancer staging procedures.[42]

A word of caution, though: "[T]he incorporation of 3DUS [3D ultrasound] into clinical practice…will require more than visually appealing images or praise regarding the diagnostic possibilities…." as such representation must also improve on available clinical information.[43]

The miniaturization of ultrasound as a hand-held, bedside diagnostic instrument[44] and the use of ultrasound to deliver gene transfer and gene therapy[45] are two emerging applications of ultrasound technology.

The quality of sonograms is limited by the ultrasound lens itself, and its ability to detect the sound waves. Research is developing new types of materials for the ultrasound lens, as the size of the ultrasound device itself must be at least as large as the sound waves it is trying to detect. Novel detection materials offer benefits to miniaturise this technology.

TABLE 5: POTENTIAL DEVELOPMENT OF ULTRASOUND

Present	Emerging Developments	Emerging Technologies
Echocardiography (3D, 4D) Echoencephalograpy Elastography High Frequency Doppler Ultrasound Mammary Ultrasonography Microbubbles Enhanced	Further miniaturisation Non-expert users New contrast agents More complex transducers Improved spatial resolution Wider use of 4D ultrasound Ability to distinguish between malignant and benign tissue Expanded use in cancer staging Further involvement in integrated therapy Embedded artificial intelligence Functional and molecular applications	Hand-held robotic and remote ultrasound Magnetic Resonance Guided Focused Ultrasound (discussed under hybrid technologies) Hybrid Ultrasound Device (see hybrid technology discussion)

2.3: Magnetic Resonance Imaging [MRI]

MRI is an established imaging method. Accurate assessment of the liver, spleen, pancreas, bile ducts, vascular structures, and retroperitoneal organs (e.g., the kidneys, the collecting system, and the adrenals) are possible on MR imaging. Over the last 10 years, a number of technological advances have allowed real-time MRI to guide cardiac catheterization, improve image quality, shorten scanning times, and with open magnets allowing improved access for the patient.[46] MRI allows differentiation between sub-endocardial and sub-epicardial perfusion, and emerges as a potential alternative non-ionising technique to evaluate myocardial perfusion. MRI is also the optimal non-invasive method for assessment of articular cartilage.[47]

The intravenous administration of MR contrast agents can frequently improve the analytical capability and provide diagnoses that are more specific.[48]

Animal studies showed that MRI-guided diagnostic catheterization, balloon dilation, stent placement, valvar replacement, atrial septal defect closure, and radiofrequency ablation are feasible procedures and may have potential clinical applications. One expert predicted that MRI-guided catheterization has the potential to replace the current X-ray-based diagnostic and interventional procedures for children with congenital heart disease, avoiding all radiation exposure while improving soft tissue imaging.[49]

Experts believe that the future development of MR technology will be less concerned with increasing computational power, higher bandwidth graphical displays, faster computer networks, improved pulse sequence architectures, or improved technical specifications. The combination and integration of MRI into multiple systems or modalities will be the enabling technology platform that will drive image-guided intervention and maps out the future of interventional MRI.[50]

Contrast agents enable faster scanning especially when coupled with technical advances in the speed of the imaging itself. This means that scan times can avoid having the patient hold their breath during the scan, or synchronise the scanning with the relevant body movement. This leads to the ability to study physiologic processes, such as cardiac or cerebral perfusion imaging. However, patient motion can affect even cranial MR images.

The future of functional MRI[51] in neurosurgery points to increased use where tumours are co-located with active areas of the brain and in understanding physiological bases for cognition and perception.[52]

Diffusion MRI is a quantitative, MR technique that has been shown to be potentially useful for the study of multiple sclerosis, due to its ability to assess the presence of tissue damage in the so-called normal-appearing white and grey matter of the brain.[53]

Current field strengths of MR devices are seen as increasing. Current devices operate between 0.5 and 1.5 Tesla [T], but devices with 3+T exist and research machines up to 8T exist. Increasing field strength offers technical improvements in the signal-to-noise ratio, which means that spatial resolution is improved. [54] [55]

2.3.1: Magnetoencephalography [MEG]

MEG offers sophisticated 3D functional mapping of the brain by measuring the magnetic fields created by the electrical activity of neurons with millimetre spatial accuracy in real-time. Physics is driving the development of this technology with the benefits of "superconducting quantum interference devices" known as SQUIDS, cooled to the temperature of liquid helium, permitting measurement of very small magnetic fields. MEG images can be overlaid with MRI anatomical images.

At present, clinical applications focus on pre-surgical brain mapping (visual, auditory, motor cortex and other functional areas of the brain) as well as the evaluation of epilepsy. However, interest in other neurological disorders is developing.

A UK foresight study on neuro-imaging and addictions concluded that the benefits of MEG were substantial and that there should be plans to increase the numbers of MEG units from the current single unit level.[56]

At present, it is uncertain whether MEG will replace the current reliance on the electroencephalogram (EEG), as the technology of choice; however, EEG does not, unlike MEG, require the patient to be motionless during the scanning process. EEG also has lower investment costs and is readily available and used in outpatient clinics, in comparison with MEG, which in its current state of development, requires a fixed installation. The technology is widely available in Japan, while Canada manufactures MEG devices.[57]

TABLE 6: POTENTIAL DEVELOPMENT OF MAGNETIC RESONANCE IMAGING

Present	Emerging Developments	Emerging Technologies
Functional MRI MR Angiography MR Cholangio-Pancreatography Diffusion MRI Echo-Planar Imaging MR Cine Imaging (Wall Motion Studies) MR Spectroscopy Magneto-encephalography	New contrast agents Further development as replacement for invasive procedures MR-guided cathertisation Integration with other technologies and clinical applications Higher field imaging (3 to 8 Tesla) Real-time monitoring of treatment Improvements for patient comfort Understanding of cognition Uncertain whether MEG will replace EEG	Integration with other technologies Image-guided therapy and surgery and robotics

2.4: Tomography And Nuclear Medicine

Nuclear medicine technologies are widely used in Ontario's hospitals in various medical procedures including diagnosing coronary artery diseases, performing myocardial perfusion and wall motion studies, quantifying blood flow in various anatomical organs including the brain, staging cancer development, and detecting joint and hip degeneration.[58]

Medical imaging is one particular type of diagnostic technology that has proved to be particularly innovative. Imaging, too, is seen to be a key element across the whole clinical process. In addition, technical enhancements and improvements in aspects of the imaging technology, such as in the detector systems, offer opportunities to reduce sources of signal noise and costs while improving quality of the readout of images.

Experts identify a number of areas of technological advancements in the field of nuclear medicine:

- the development of new radiopharmaceuticals and detector technologies,
- more economical and dedicated scanners,
- digital technologies including software, storage devices and telecommunications, to enhance imaging processing,[59]
- higher resolution gamma cameras,[60]
- addition of embedded intelligence through artificial intelligence.

2.4.1: Computed Tomography (CT)

One of the most commonly used diagnostic technologies in Ontario, CT has reached a very high degree of maturity, mastering almost all clinical demands since its beginning. CT has evolved rapidly since its invention in 1972, but its demise had been predicted from advances in MRI and ultrasound. Some suggested that CT would be replaced by MRI.[61] However, PET/CT hybrids, first predicted in the mid 1990s, were rapidly developed and announced in 1999.

Since then, CT has evolved and in some respect been resurrected by the introduction of slip ring technology that allows continuous data acquisition and the introduction of spiral and multi-slice detectors that enables the scanning of organs and anatomical regions continuously within a very short time.[62]

Most of the clinical benefits of a multi-slice, 64-slice, CT system focus on imaging the heart. Technological improvements continue in the application of cardiac CT, where effective scan times of 50 minutes are desired and being developed, and perfusion measurements, where scanning of larger organ and anatomic ranges demands higher coverage. [63]

Housefield, the inventor of the CT, based the measurement model on the radio-density of distilled water at a standard temperature and pressure. There is a view amongst some developers that this measurement model is a design constraint that should be overcome: "for sustained innovation and for the long-term future of CT, it will be important to extend the range of

applications and to offer more than just images depicting Housefield units. To 'escape from the HU cage' is a declared goal".[64]

The evolution of multi-slice CT has opened up new frontiers in diagnostic imaging. The technology was shown to have an advantage over others in the field of interventional neuroradiology with the ability to separate venous from arterial flow using computed tomography angiography. The Canadian Association of Radiologists has identified several areas for CT innovation.

Separate work has organised CT development into generations, showing that the first three generations focused on enhancements of the original underlying technology, while the 4th generation is distinguished by advanced computational modelling and real-time or 4D imaging.

TABLE 7: GENERATIONAL MODEL OF CT SCANNERS[65]

Generation	Brief Description
I	Single beam with one or two detectors; x-ray source rotation of 1 degree
II	Fan-shaped beam with multiple detectors; decrease in scan time; rotation increased to 30 degrees
III	An array of detectors, fixed table, 3D images
IV	360 degree ring of detectors, moving table; 4D images

The 5th generation developments appear to be pointing toward significant refinements in the existing technology (smaller and safer being key features), with networking capabilities and embedded intelligence. Other technical developments of CT include faster imaging, novel X-ray tubes, detectors, imaging reconstruction and display, dedicated CT for trauma diagnosis, low cost C-arms and mobile units.[66] Most have been or are on their way to being achieved.

At present, there are only a few fields of application that demand further technological development in CT. For instance, prioritising a faster imaging pulse, i.e. cycle through an image capture sequence quicker, would shorten the total overall acquisition time. This produces improved productivity for the technology, but offers improvements in image contrast as more images are assembled for a given total time.[67]

The pivot of the future for CT, though, lies in the development of CT hybrids, i.e. PET/CT (see the section on Hybrids), and it is here that the potential impact on clinical practice should be assessed.

In addition to the potential for hybridisation, evolution of the gamma cameras used in imaging will evolve, such as adoption of applications from space science. The Bioimaging Unit at the University of Leicester, UK, and its Space Research Centre have developed a prototype hand-held gamma camera for cancer diagnosis.[68]

Virtual Colonoscopy is a further development of CT, producing colonographies without the usual colonoscopy tube or the use of Barium. This illustrates how CT technology is driven by non-invasive objectives, and the desire to reduce patient discomfort.

2.4.2: Positron Emission Tomography [PET]

The clinical application of nuclear medicine also expands to more organ-based diagnosis where there have been demonstrations of the successful measurements of renal blood flow using PET leading to its potential applications in the diagnosis of reno-vascular diseases. [69]

PET is recommended as a complementary technology to conventional methods (computed tomography and bone scintigraphy) of cancer staging in that it provides better sensitivity in detecting nodal and bone metastases.[70]

It is acknowledged that there is a need to learn whether the high diagnostic accuracy of PET, combined with more rapid patient throughput, offsets the higher costs. Experiments suggest a key role in work-up of patients with suspected or proven coronary artery disease.[71]

A promising area is the development of designer PET probes that can be produced with exquisite sensitivity and ability to function in a hybrid arrangement with anatomical devices. 18F-fluorodeoxyglucose positron emission tomography (FDG-PET) has been used for detection, staging, and response monitoring in breast cancer patients.[72] It is predicted that future work using other PET probes besides FDG will undoubtedly improve our understanding of tumour biology and help tailor therapy to individual patient by improving our ability to quantify the therapeutic target, identify drug resistance factors, and measure and predict early response.

In addition, the application of PET to gene therapy and the use of reporter genes is seen as offering improved diagnosis and management of patients with, for instance, ischemic heart disease. [73]

Addressing the costliness of PET has produced PETRRA, seen as a low-cost PET imaging technology using novel technology current in prototyping. It is anticipated to have equivalent performance to current PET technology in terms of sensitivity, and spatial and temporal sensitivity but with significantly lower costs with suggested faster patient throughput.[74]

2.4.3: Single Photon Emission Computed Tomography [SPECT]

Myocardial perfusion imaging is important for the management of patients with suspected or known coronary artery disease. The improvement of single-photon emission computed tomography flow agents is seen as greatly enhancing the detection and measurement of myocardial extraction and the cardiac uptake proportional to blood flow.[75]

Because of limited availability of PET equipment, much effort has been invested in expanding the clinical application of SPECT for medical imaging.[76]

TABLE 8: POTENTIAL DEVELOPMENT OF TOMOGRAPHY AND NUCLEAR MEDICINE		
Present	**Emerging Developments**	**Emerging Technologies**
Multi-slice CT Positron-Emission Computed Tomography (PET) Single-Photon Emission-computed Tomography (SPECT) X-Ray Computed Tomography	New contrast agents Molecular-level imaging More economical scanners with improved image processing Higher resolution gamma cameras 4D imaging Located in non-traditional settings Faster cycle time to capture an image and general reduction in scan times Decrease in use of cardiac cathertisation	Computed Tomographic Colonography Digital Tomosynthesis PETRRA Hand-held gamma camera Develop of hybrid technologies

2.5: Hybrid Technologies

PET has been less used clinically than SPECT because of high cost and reimbursement practices of many countries, limiting clinical availability.[77] PET and CT complement each other's capabilities with current evidence pointing to effective use in primary diagnosis of patients with tumours; it is likely to emerge as the method of choice.[78] [79]

The main difficulty with PET is the lack of an anatomical reference frame even though PET has high sensitivity in identifying of areas of cancerous involvement at an early stage. The combination of PET with another modality, such as CT, improves adds potential clinical applications. Addition of CT to PET improves specificity, but also sensitivity, while the addition of PET to CT adds sensitivity and specificity in tumour imaging. One study demonstrated PET/CT to be a more accurate and faster than either of its individual components; it may be better than side-by-side viewing of images from both modalities.[80] The faster PET/CT diagnostic procedures may lead to a higher patient throughput and a more comfortable examination, which typically last 30 minutes or less.

The Canadian Association of Radiologists identifies PET/CT as a driver that will shape the future of medical imaging in Canada[81] as PET/CT enables one test to provide both functional and structural information. There are six PET/CT scanners installed in Canada as of January 2005; three of these are in Ontario (the Ottawa General, the Princess Margaret Hospital and the Sunnybrook Regional Cancer Centre). Currently, the hybrid technology is available only to

people participating in clinical trials in Canada (slated for completion in 2006). Subsequent deployment may depend on the results of this trial.

The other advancement in hybrid technology includes the development of an integrated system for PET and MRI. Magnetic resonance imaging is excellent for morphological imaging with a high anatomical resolution, but it lacks functional/metabolic information. The development of the whole-body PET/MRI helps to promote a promising diagnostic modality for oncological imaging in cancer screening.

Hybrid technologies are still viewed as experimental, but are gaining evidence-based support for their analytical capabilities to include both anatomical and physiological information. The ability to improve the diagnostic accuracy, in combination with shortened scanning time and procedures should have an advantage in improving diagnostic workload management and productivity. Continuing development points to the emergence of hybrid systems tailored to overcome specific technical limitations of component technologies.[82]

There may also be developments to consider from research using micro-PET/CT and micro-SPECT/CT used with small animals for determining specific gene function in biomedical research. There is a view that these micro-technologies may be a baseline for the next generation of imaging technologies.[83]

Finally, there is considerable interest in hybrid technologies for their ability to make 'one-stop' diagnosis (and treatment). Cardiac diagnosis is an example.[84]

The trend to hybridising imaging technologies as a general approach is gathering pace, as the weaknesses of one type of technology are compensated with capacities in another. The next generation diagnostic device can be seen as more generally a hybrid technology, drawing on these features:

- improvement in spatial resolution of molecular imaging,
- development of new contrast media,
- specific tracers which 'personalise' the imaging to the individual patient,[85]
- move from anatomical to functional and molecular applications,
- embedded intelligence through artificial intelligence capabilities.

2.5.1: Magnetic Resonance Guided Focused Ultrasound

This is a non-invasive integrated therapy system, which combines MR thermal imaging to guide and control ultrasound beams to heat tissue to destroy it. The MR component provides 3D images to locate the site. The MR thermal imaging permits real-time monitoring of the treatment to ensure both that the required temperature has been reached and that the tissue has been destroyed. The technology is not widely available in Ontario.

2.5.2: Stereotactic Radiosurgery

Stereotactic radiosurgery is a non-invasive integrated therapy combining a treatment intervention with imaging technology. There are, at this writing, two in Ontario, one at the University Hospital Network's Toronto Western Hospital and one at the Ottawa Hospital Regional Cancer Centre.

This technology falls into the category of image-guided therapy, since imaging technologies are coupled with a way of delivering a highly focused radiation dose to a tumour site. Having begun as a tool mainly for neurosurgery, it is increasingly being exploited in other locations. The benefits include being able to reduce the total treatment time, perhaps from 6 to 8 weeks to less than a week. Indeed, integrated diagnostic and treatment technology offers the general possibility of same-day diagnosis and treatment in an ambulatory setting.[86]

TABLE 9: POTENTIAL DEVELOPMENT OF HYBRID DEVICES

Present	Emerging Developments	Emerging Technologies
Hybrid PET/CT Stereotactic radio-surgery Magnetic Resonance Guided Focused Ultrasound	Increasingly replacing invasive procedures Earlier detection of e.g. coronary heart disease Imaging of inflammation	"one-stop" diagnosis and treatment customised hybrid systems for specific clinical situations

2.6: Diagnostic X-Ray

The Canadian Association of Radiologists identified that teleradiology and image-guided interventional radiology are potential disruptive technologies that will revolutionise diagnosis.[87]

Common X-ray technologies and procedures include fluoroscopy, mammography, dual-energy X-ray absorptiometry and angiography. Many X-ray technologies remain the "gold standards" for diagnosing disease conditions, such as mammography for breast cancer detection and angiography for coronary artery disease.

X-ray radiography research has a key focus on reduced radiation exposure for patients, faster and more sensitive X-ray detection, digitising detection and image conversion signals as well as improved image spatial resolutions through flat panel detector technologies.[88] In the short-term, there should be continued improvement (reduction) in radiation exposure, increased use of computed radiography along with the increased infrastructure capacity for digital image storage and transfer (RIS and PACS). However, should public stakeholders become more salient of the rising radiation dosage at the population levels due to increasing use of X-rays, there is the possibility that there would be calls for substitution in favour of non-X-ray modalities.

Ontario has reviewed scintimammography technology[89] as a second-line technology. Future interest in this technology will depend on smaller gamma cameras, including semiconductor cameras. However, the key diagnostic benefit appears to be affected by the difficulty achieving improvement in external tumour detection and localisation through better contrast and spatial resolution.[90] This particular technology may not be of greater merit when compared to the future role of breast MRI.

Digital Tomosynthesis a 3D x-ray breast imaging technology, currently available only as a research tool. It involves taking multiple x-ray images and requires patient positioning as in a conventional mammogram. The procedure takes about 7 seconds and produces 11 images, which a computer program assembles into a 3D image. Digital images can be readily and quickly displayed in the radiologist's workstation and can be manipulated to optimise diagnostic information with digital tomosynthesis providing the key step into three dimensions, thus avoiding the potential concealment of tumours from current practice of stacking up 2D images with the attendant 'noise' of the other layers clouding the image itself. One would expect a potential benefit to be the reduction the recall rate for screening mammograms, and a corresponding reduction of the radiation dose. The move away from film-based technologies is accelerated as a result with technologies such as this that improve the efficiency of the breast imaging process itself.[91]

This technology is described by many as having considerable future benefits, but requires further study to assess the diagnostic benefits.[92]

TABLE 10: POTENTIAL DEVELOPMENT OF DIAGNOSTIC X-RAY

Present	Emerging Developments	Emerging Technologies
Scintimammography	Reduced radiation More sensitive digital detectors	Digital tomosynthesis

2.7: Photonics, Optics And Spectroscopy

Operating at the level of photons, new diagnostic opportunities are emerging with particular interest in the infra-red and near infra-red spectrum. At the present stage of development, this is an entirely new class of diagnostic technologies, offer considerable benefits such as improved resolution, but also it is non-invasive and readily interpreted. Developments here are closely linked to the nano-technology and quantum physics. There is interest in bioluminescence, exploiting the ability of quantum dots to fluoresce at different wavelengths depending on their size.

The use of light of various frequencies through non-invasive fluorescent spectroscopy offers the opportunity to stimulate fluorescence within tissue to diagnose. Technology to diagnose Type II diabetes, without patient fasting, using this approach already exists,[93] offering a one-stop diagnosis as the patient does not need to go to a laboratory for tests as the physician interprets the results immediately.

Optical coherence tomography [OCT] may be considered the optical version of ultrasound, using a near-infra-red light source to produce a high-resolution image of tissue. Image resolution is 2-30 μm, compared to the 200-300 μm of ultrasound. The technology is however limited to 2-3 mm of tissue penetration. Research at the NRC is exploring the combination of OCT with fibre optic endoscopes to capture images within the body.[94]

Near-infra-red spectroscopy[95] is a non-invasive and non-ionising imaging modality which provides information on oxygenation of haemoglobin, producing a picture of the oxygenation of tissues. The technology is portable, comprising a fibre optic probe, detectors, a laptop computer and small piece of hardware.[96] Immediate application is in brain functioning. A version of this technology is called *spatially resolved spectroscopy*, a technology transfer from astronomy. The technology is evolving showing promise for "bedside cerebral blood flow measurements and as a cerebral imaging modality for mapping structure and function". [97]

Raman spectroscopy is not new but it exploits the tendency of monochromatic light to be scattered or absorbed when directed at a molecule, at the same frequency as the incident light. A small fraction of light (about 1 in 10 million photons) will scatter at a different frequency. Clinically, this behaviour of light can be used to gather biochemical information on proteins, fats, etc.[98] Its use in cancer diagnosis has been reported. [99]

Hand-held and easily portable diagnostic devices are of particular interest in emergency response vehicles, and critical care activities where time is of importance, and is seen as an area for rapid change in the next 5 years. Optical/photonic developments appear to be of future benefit as the technology is seen as amenable to being small, portable, and easy to use and interpret.[100] [101] [102]

TABLE 11: POTENTIAL DEVELOPMENT OF PHOTONICS, OPTICS & SPECTROSCOPY

Present	Emerging Developments	Emerging Technologies
Bioluminescence Confocal Microscopy Diffuse Optical Imaging Fluorescent spectroscopy Optical Projection Tomography Raman Spectroscopy	Polymer-encapsulated, bioconjugated quantum dots	Near Infra-red Spectroscopy Spatially-resolved Spectroscopy Optical Coherence Tomography

2.8: Wireless Or Networks

An area of potential development is based on the continuing evolution of the internet and wireless technologies; this will broaden access to technologies, as well challenge many organisational approaches to locating diagnostic technologies. In its broadest sense, this is about e-health, telemedicine and developments in that genre.

For example, the convergence of wireless network technology (e.g. the mobile telephone) and biometric sensors offers patients the opportunity for home-based monitoring of their health status. There is a well-developed e-health literature on the use of biometric sensors for home-based health monitoring as part of a comprehensive e-health infrastructure. There is discussion of a new endoscopic technology which combines wireless telemetry with video. Other wireless technologies being explored for application include oesophageal pH monitoring, the subject of a recent technology assessment.[103]

E-health capabilities lead naturally to considerations of the skills and knowledge of people in remote locations to take advantage of these capabilities. Many e-health experiments explore the use of diagnostic technologies by non-specialists.

2.8.1: Bio-sensors

The use of wireless technologies in monitoring patients for sleep apnea is well-established. However, the use of short-range – a few metres -- wireless communications (coupled with mobile phones is a new development providing wireless links between the sensors, worn by the patient, and the mobile telephone which provides the link to the clinician in a remote setting. Its developers see this technology as rivalling traditional polysomnography.[104] [105]

2.8.2: Capsule Endoscopy

Capsule endoscopy utilises a small, pill-sized, video capsule to investigate the part of the gastrointestinal tract that cannot be reached by traditional means. It represents a significant advance in the investigation of small bowel diseases and the beginning of wireless endoscopic imaging. This emerging technology is gaining ground due its relatively simple and painless procedures. Its use has been proven in diagnosing suspected small bowel bleeding and represents an improvement over Barium radiographic methods.[106] The role of capsule endoscopy continues to evolve as it expands its clinical applications in the investigation of inflammatory bowel disease, iatrogenic disease, polyposis syndromes and coeliac disease. It is likely that in many instances it will become the next test after standard endoscopic evaluation.[107]

2.8.3: E-health Technologies

The European Commission funded project, OTELO, is a portable ultrasound system permitting non-specialists to use a system producing safe and reliable echographic diagnoses.[108] The key benefit of tele-echography is to provide medical expertise at a distance to remote locations lacking local ultrasound expertise. OTELO is a portable ultrasound probe holder, built around a robot, to reproduce the expert's hand movements during an ultrasound examination.[109] [110]

Colposcopy is used in the diagnosis of cervical cancer and precancerous lesions. The research suggests that remote colposcopy – telecolposcopy -- with images transmitted over a network are at least as good as on-site diagnosis. This example illustrates the increasing potential of the use of remote diagnosis, and digital imaging. [111] [112] Research has also established telecolposcopy as a diagnostic tool in primary care.[113]

Doc@home™ is a hand-held device, remote-monitoring, home-based device for sending various types of health information to a central location. It is a commercial service currently available in a number of European countries. [114] There are many such technologies in development.

TABLE 12: POTENTIAL DEVELOPMENT OF WIRELESS OR NETWORKED DEVICES

Present	Emerging Developments	Emerging Technologies
	Convergence of wireless telemetry with bio-sensors, video and internet Non-specialist users of networked diagnostic equipment Wireless home-health monitoring E-health diagnostic platform	Capsule Endoscopy Tele-echography Tele-colposcopy

2.9: Electro-mechanical Diagnostic Devices

Novel developments here are exploiting non-traditional diagnostic approaches, but the foresight and horizon scan papers did not identify any specific trends.

The development of the electronic nose did emerge from the literature search, as an example. This is a non-invasive, point-of-care diagnostic technology that is currently of considerable research interest.[115] We know the first electronic nose as the Breathalyzer, developed in 1954, to detect alcohol in exhaled breath.

Animal studies have suggested their noses are sensitive to the distinctive odours caused by infections and metabolic diseases. *Heliobacter pylori* can be detected by looking for ammonia in the breath while diabetes produces acetone. At present, there is interest in its application in the detection of renal failure, pulmonary tuberculosis, lung cancer, pneumonia[116], and sinusitis.

Leading research is being conducted by the Sensors Research Laboratory, University of Warwick (UK) which has an interdisciplinary electronic nose group.[117] Canadian research in this area is reported as limited.[118]

TABLE 13: POTENTIAL DEVELOPMENT OF ELECTRO-MECHANICAL DEVICES

Present	Emerging Developments	Emerging Technologies
		"Electronic Nose"

2.10: Contrast Agents And Radiation Probes

The use of molecular imaging technology is restricted to a few modalities. The computed tomography and ultrasound based approaches represent a good fit of using molecular imaging in medical diagnostics. These types of diagnostic technologies are based around standard radiation probes of x-rays, gamma rays, radio-frequency signals and ultrasound waves. Advances with other radiation probes are expected in the use of visible and infra-red light, microwaves, terahertz waves and further development of magnetic and electric fields.[119] Developments here will work in partnership with nanotechnology, specialised computer hardware and software – in particular embedded intelligence and robotic vision.[120]

Radiopharmaceuticals enhance the study of molecular processes and biological pathways along with anatomical information. Dedicated radiopharmaceutical molecular tracers (Rubidium^{82}, Nitrogen^{13} ammonia for PET and Thallium^{201} and Technetium^{99} for SPECT) enhance the analytical capabilities of both PET and SPECT, and PET is more accurate than SPECT, providing better quantitative results.[121]

Contrast agents improve the diagnostic capabilities of various technologies and increase the specificity of diagnosis. MRI is one area where contrast agents are being developed to significantly expand this technology's effectiveness. Contrast agents help reduce sources of inaccuracy arising from long acquisition time – and overcome, for instance, the effects of the patient movement.

As an example, contrast agents have extended the range of abdominal applications, permitting MR imaging of the small bowel and the colon. Developments in contrast agents are taking place along three lines of potential:[122] [123] [124] [125] [126]

- applicability to different aspects of the anatomy (e.g. liver, spleen, vascular system),
- increasing the precision of the targeting or distribution (extracellular, intravascular, reticuloendothelial),
- shortening testing times with corresponding reduced radiation dosage.

A number of highly paramagnetic probes (probes that are only magnetic in the presence of an imposed magnetic field) such as iron oxide or gadolinium nano-particles have been used for MRI applications. With the improvement and development of more dedicated radionuclides, MRI, which has high spatial resolution and unlimited depth penetration, is expected to become a good modality for molecular imaging.

Quantum dots have been specifically identified as a nanotechnology of interest.[127] A quantum dot is a "semiconductor nanostructure" which has specific properties making it possible for them to replace organic dyes, to provide a higher technical standard with greater flexibility in use.

While MRI is effective at imaging soft tissue, difficulties using it to image open spaces, such as the lungs, have resulted in the continuing use of CT for this purpose. However, the use of hyperpolarised gases (gases that have had their molecules aligned (polarised) by a laser) has created the opportunity to image voids filled by these gases and thus diagnose, for instance,

breathing patterns. This offers a new contrast medium, which also creates a whole new imaging platform within the MRI technology.[128] [129]

TABLE 14: POTENTIAL DEVELOPMENT OF CONTRAST AGENTS AND RADIATION PROBES		
Present	**Emerging Developments**	**Emerging Technologies**
^{82}Rubidium	New contrast agents	Hyperpolarised imaging
Nitrogen-13 ammonia	Hyperpolarised gases	Bio-conjugated quantum dots
^{201}Thallium	Microwaves, light spectrum	Iron oxide or Gadolinium nano-particles
^{99}Technetium	Terahertz waves	
X-rays		
Ultrasound waves		
Gamma rays		

2.11: Taxonomy Of Emerging Diagnostic Technologies

Based on the foresight and horizon scan results, an approach to understanding change in diagnostic technologies can be proposed.[130]

Early-generation technologies focus on the initial clinical application that the device is designed for – it is the device as it is invented. Generation II moves the device forward with refining accuracy, speed, capabilities, and perhaps improvements in materials of construction and the scale of the device, but it is still recognisable as the device as invented. Subsequent generations extend functionality, applications as other people test additional capabilities.

While improvements in the device's materials and constituent built components offer continuing areas of innovation, a key step is the introduction of microprocessor capabilities, and this can involve three areas:

- Automating the operation of the machine's functions,
- Digital image capture, storage and processing,
- Software to interpret the images.

It is the last that is seen as defining future evolution from Generation III technologies as it is in the integration of software into the device that embedded intelligence, diagnostic algorithms, robotic vision and image interpretation emerge. Many foresight studies suggest the emergence of 'smart machines', with significant interpretative capabilities.

It is suggested that diagnostic technologies of disruptive interest are more likely to emerge at Generation III having evolved through the first two generations as prototypes. They will then

quickly evolve their computational capabilities initially as a standalone device (Generation IVa) and then within a networked (Generation IVb) environment. The evolution into the latter will actually depend on whether the future health infrastructure has widely adopted networking and e-health as a matter of course. Continuing evolution of the underlying physics and materials technology will continue to improve the diagnostic device but these technological advances will exploit enhanced computational capabilities. This seems to have been the pattern of development of MRI, CT, and SPECT to date.

The currently evolving development paradigm, therefore, will see technologies become networked, their use distributed, while embedded intelligence enhances ease of use and ability to produce reliable results. Generation V appears to embrace all the key developments foreseen by both the Japanese and Microsoft Foresight studies.

TABLE 15: GENERATIONAL MODEL OF THE EVOLUTION OF DIAGNOSTIC TECHNOLOGIES

Generation	Description	Defining Features	Electro-mechanical development
I: introduced device	Basic stand-alone electro-mechanical technology	Focused on specific anatomy; electro-mechanical devices	Continuing evolution and adoption of new materials Refinements in size, portability, sensitivity of device itself Improvements in data capture and storage technologies Refinement and improvement in the patient's experience of the technology
II: enhanced device	Enhancements of the basic technology (e.g. bigger image, more detectors, greater sensitivity, shorter time). Technology still operates as in Generation I	Focused on specific anatomy; electro-mechanical devices	
III: microprocessor device	Microprocessor-based processes enhance ability to interpret data	Faster, data manipulation of improve visualisation, digital data capture and storage/retrieval	
IV a: stand-alone computational device	Greater computational capabilities coupled with basic algorithms analyse data	"Computational" capabilities, 3D and 4D imaging; equipment still large, standalone technology	
IV b: integrated computational device	Technology moves from stand-alone to degree of integration with other clinical activities, including through networks and links to remote locations	Technology begins to integrate clinical processes as it becomes smaller, faster, safer, easier to operate	
V: smart device	Information processing through artificial intelligence, or neural networks; device becomes a 'technological assistant'	New diagnostic insight and knowledge through embedded machine intelligence	

Based on the findings, it is also now possible to produce an **Emerging Diagnostic Technologies Taxonomy** revising the taxonomy presented at the beginning of the report.

Compared to the original version of this diagram, important developments for future consideration are identified. Perhaps most obivous is the suggested addition of a new class of diagnostic technology: **Photonics, Optics and Spectroscopy**. This is a rapidly evolving area of development, is characterised virtuously as non-invasive, with minimal use of radioactivity. Sensitivity is high as is resolution.

Technologies that are in experimental or early development including proto-typing that were of interest in the foresight studies are identified in **Focus of Interest**.

New Technologies shows the emergence into the diagnostic arena of molecular diagnosis, integrated technologies, and technologies using networks and communications systems.

Diagnostic e-health is identified in the row **Wireless or Networked**. Networking is becoming very important, not just for e-health implementation but as a continuing exploitation of the internet and reflects developments across a full spectrum of applications. Coupling networks with wireless technologies, and linking sensors and telemetry such as mobile telephones, creates a type of diagnostic freedom, permitting diagnostic information to be gathered anywhere in real-time. Finally, the evolution of hybrid diagnostic/therapeutic systems, **Integrated Systems**, identifies the key technologies seen as good examples of this.

TABLE 16: EMERGING DIAGNOSTIC TECHNOLOGIES TAXONOMY

	Ultrasound	Magnetic Resonance Imaging (MRI)	Radiography	Tomography & Nuclear Medicine	Photonics, Optics & Spectroscopy	Electro-mechanical
Existing Technologies	Echocardiography Echoencephalo-graphy Elastography High Frequency Doppler Ultrasound Mammary Ultrasonography	MR Angiography MR Cholangio-Pancreatography Diffusion MRI Echo-Planar Imaging MR Cine Imaging MR Spectroscopy	Angiography Arthrography DEXA Diagnostic X-Rays Fluoroscopy Myocardial Perfusion Scintigraphy Multiple Gated Acquisition Scan Scintimammography	Positron-Emission Computed Tomography X-Ray Computed Tomography Multi-slice CT		Audiometry Electrocardiography Electroencephalo-graphy Electromyography Plethysmography Polysomnography Spirometry

TABLE 16: EMERGING DIAGNOSTIC TECHNOLOGIES TAXONOMY, CONTINUED

	Ultrasound	Magnetic Resonance Imaging (MRI)	Radiography	Tomography & Nuclear Medicine	Photonics, Optics & Spectroscopy	Electro-mechanical
Focus of Interest [Not all existing technologies have been mentioned in foresight studies. That a technology is absent does not necessarily mean that it lacks potential only that it was not included in any of the foresight studies reviewed.]		Magneto-encephalography Functional MRI	Neuroradiography Digital Tomosynthesis Handheld Gamma Camera	Hybrid PET/CT Single-Photon Emission-computed Tomography	Bioluminescence Confocal Microscopy Diffuse Optical Imaging Fluorescent spectroscopy Near Infrared Spectroscopy Optical Projection Tomography Raman Spectroscopy Spatially Resolved Spectroscopy Optical Coherence Tomography	Olfactory sensors

TABLE 16: EMERGING DIAGNOSTIC TECHNOLOGIES TAXONOMY, CONTINUED

	Ultrasound	Magnetic Resonance Imaging (MRI)	Radiography	Tomography & Nuclear Medicine	Photonics, Optics & Spectroscopy	Electro-mechanical
New Technological Approach	Handheld ultrasound					
	Molecular Diagnosis					
New Integrated Clinical Technology	Magnetic Resonance Guided Focused Ultrasound			Stereotactic radiosurgery		
Networked or Wireless Diagnostic Technology	Tele-echography				Tele-colposcopy	Bio-sensors Capsule endoscopy
	E-health distributed diagnostic platform					

3: Trends Relevant to Diagnostic Technologies

The foresight studies and horizon scan papers reviewed have explored likely future technological developments, over the next 5 to 15 years and more. The material in this section draws on the information to identify key trends. This section also serves as a summary of the technological changes put into the context of health system development.

Roadmaps present these developments, with approximations of by when one might expect to see the emergence of the identified technology or capabilities. Foresight projections, though, attempt to find a balance between when technological developments will come to fruition and when the technology or change can be expected to appear in clinical practice. The latter can be influenced by explicit policy.

3.1: General Health Trends

An important trend is refocusing health systems on health promotion and disease prevention.[131] This is a systems-based approach to healthcare priorities and outcomes. It also puts the interests and needs of the patient at the centre of healthcare priority setting, rather than on the interests and needs of health professionals and provider institutions. This realignment will have a continuing influence on how health systems allocate resources and set priorities for service delivery.

It is still not yet well understood what a diagnostic 'system' would look like given the current practice of seeing diagnostics as a separate, standalone, capability. The emergence of integrated diagnostic/therapeutic devices and practice (called "theranostics") point to potential disruption of traditional practice.

Cost-containment, a continuing concern, is being challenged by an alternative view that sees health expenditures as investments, driving wider benefits for the economy.[132] In many cases, cost-containment is being redefined as value-for-money, putting the emphasis on healthcare expenditure to release specific health outcomes and benefits, with a corresponding realignment of system financing toward a result-oriented approach.[133] As efforts to define health outcomes for patients, it should be expected that identification of diagnostic outcomes to inform value-for-money, identify investments in technology, or to structure service delivery, would be necessary.

Improved population health data and data modelling is helping to identify high-cost and high-utilisation individual users as well as patterns of chronic and long-term ill-health which appear to be acting as cost drivers. Most recently, US research identified a driver of Medicare expenditure growth as being individuals who are being treated for five or more conditions.[134] Diagnostics acts a gateway to clinical pathways, and to subsequent patterns of resource use based on diagnostic information. The extent to which diagnostic information can guide the identification of patients or cohorts at high risk, high cost or high utilisation will become increasingly important, as better outcomes will be associated with more precise targeting of resources proceeds.

3.2: Foresight Health Trends

Key trends from the scan and foresight literature cluster in three areas; they are developed further on the Roadmaps:

Changes in the technology

- Expansion of varieties of contrast media, with a corresponding increase in the use of 'imaged' diagnostics,
- Hybridisation of diagnostic technologies, and integration with therapeutics, with corresponding blurring of this distinction,
- Smaller, faster (real-time), safer, more mobile and more 'patient-friendly'.

Changes in the way technology is used

- Reduction in use of invasive diagnostic procedures,
- Networked and digitally integrated within the electronic health record,
- Simpler, easier to use, especially by non-professionals, with embedded artificial intelligence,
- Molecular and nanotechnology scale diagnostic paradigm,
- Migration of use, functionality, accessibility toward the clinical end-user and progressive elimination of intermediate individuals or institutions.

External factors that may influence use

- Rising population total-radiation dosages,
- Greater patient involvement in self-management including potential self-monitoring and diagnosis,
- Growth in anticipatory medicine with potential for a disease prevention approach to emerge around preventative diagnostic imaging.

3.3: Diagnostics In Non-traditional Settings

The shift of imaging technologies out of hospitals into general practice use, into people's homes, and into alternative non-hospital-based locations is anticipated as these devices become smaller, easier to use, particularly by non-specialists, and the results easier to interpret. This is seen as disruptive of the current practice of diagnostic technologies being largely hospital-based or in specialist diagnostic facilities. The wider availability of these technologies is seen as offering quicker turnaround and quicker consultations with patients and thus challenges the current logic of clinical/diagnostic pathways.[135]

The skill-mix implications are clear from trends in the technology toward requiring less specialised operators, and the integration of diagnosis with treatment. Embedded intelligence adds further to the ability to decentralise diagnosis over networks through the Internet; there is

also the possibility of nurse-robots in people's homes for clinical monitoring and data management from biosensors.[136]

While many studies focus on the potential for technologies to migrate toward community, primary and alternative care settings, this process is largely governed by other factors. The development of e-health is still in very early stages of development, but a robust e-health strategy would significantly shift the geographical distribution of technologies as well as redistribute the knowledge to use them. As well, primary care clinicians may seek to augment their skills and knowledge to embrace these newer and easier to use and interpret technologies. Developing use of evidence-based clinical guidelines continues to highlight the appropriate application of technologies and expertise with location of service provision, which can further justify redistribution outwards from centralised facilities of technology and expertise.

The foresight studies can neither assess nor anticipate the force of these changes, as there are countervailing forces, such as commitment to traditional patterns of service use or to legacy provider institutions. Funding systems may not recognise the status of alternative service providers for reimbursement, and there may be professional resistance to significant disintermediation of clinical work processes.[137]

Nevertheless, the leading edge of change is discernable, comprising the coming together of networked devices and e-health, easier to use devices with skill and knowledge redistribution, and potential to improve service outcomes through alternative models of access and service delivery.

3.4: Reducing The Burden Of Discomfort To Patients

There is a generalised concern amongst many of the papers reviewed to reduce the burden placed on the patient by the various diagnostic procedures. The invasiveness of procedures themselves has been of particular concern, with endoscopic interventions singled out.

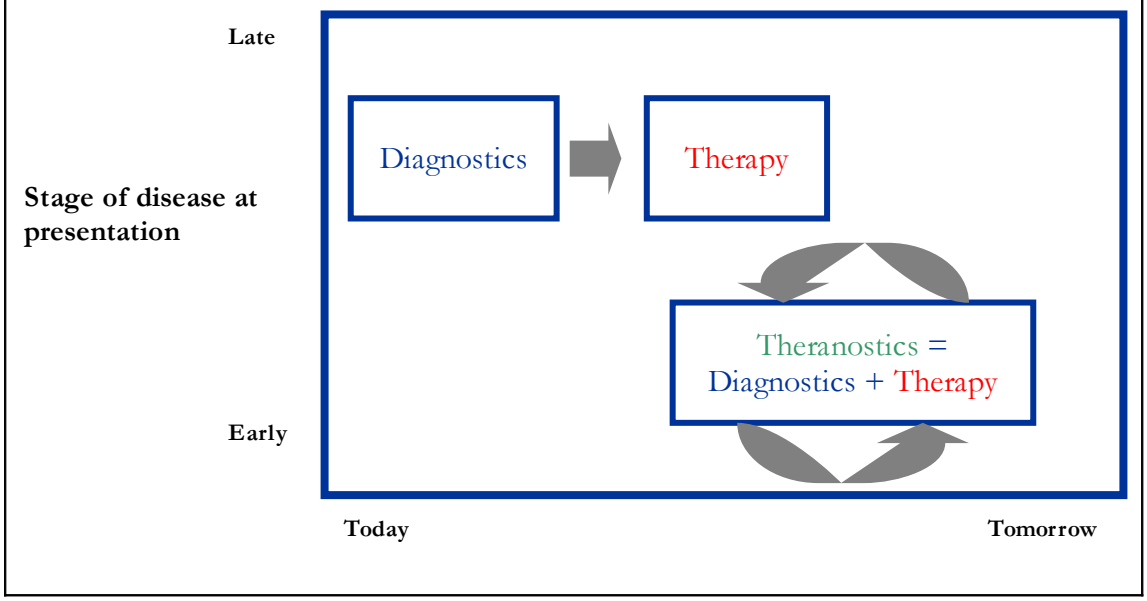
For instance, by combining scintigraphic measurements with depiction of coronary morphology through CT, there may be an increase in accuracy from linking functional with morphological data. The effect is to decrease the need for diagnostic cardiac cathertisation.[138]

Similar thinking is driving innovation in other technologies, including reducing the radiation dosage, use of analgesics, and through speedier image taking, to reduce physical discomfort on the patient.

3.5: Convergence Of Diagnosis And Treatment In Clinical Practice

The convergence of diagnostic and therapeutic capabilities is called "theranostics"[139] and it is currently being developed for application in combining medicines and therapies. Integrated therapy systems, involving diagnostic technologies such as ultrasound, MRI, CT, etc. are emerging as a combined diagnostic/therapeutic clinical platform. The full potential of imaging technologies in aiding treatment and surgery have yet to be fully understood and exploited. [140]

DIAGRAM 2: THERANOSTICS[141]



The development of integrated therapy systems offers a new surgical paradigm, which takes the current preference toward minimally invasive methods further. Substitution of simpler, easier to use technologies, e.g. the replacement of X-ray machines by ultrasound in operating rooms, while MRI and CT are seen moving into the operating room.

The implications, though, are likely to be felt in the areas already discussed in this paper, namely:

- redistribution of technologies outward from hospitals into primary care and other settings,
- redistribution of specialist knowledge along the clinical pathway toward the end-user, such as primary care physicians, cardiologist, surgeon, other professional, or patient,
- disintermediation (removal of intervening steps) of clinical and institutional workflows, in all cases toward the patient-end of the care pathway,
- collapsing the time delay between diagnosis and starting treatment,
- emergence of single, one-stop (full-service) clinical encounters,
- potential to increase patient throughput and improved clinical workflow processes,
- simplification of the technology such that it can be used by non-specialists.

3.6: E-health

The widespread research and policy interest in e-health is unfortunately also characterised by the general lack of systematic e-health services for patients despite decades of investment in the underlying technologies. The prevailing emphasis on prioritising tele-technologies for inter-professional consultations, without a clear focus on patient benefit, has slowed the evolution of

e-health, particularly into remote locations and the home, with no evident improvement in patient access.

However, the wide availability of low-cost broadband eliminates many barriers to fast and accessible distributed health services. The corresponding increase in connectivity points to the elimination of geographic distance as a barrier to the distribution of network-enabled diagnostic technologies,[142] while a number of studies have explored the potential of home-based or remote technologies.[143] [144] The likely additional capability of embedded intelligence may remove much of the need for expert operation, and thereby add to the possibility of widely distributed technologies.

A network of smaller health facilities may be thought of as a distributed (or disaggregated) single and larger facility, with diagnostic services provided across a network. Remote technologies, with either centralised or decentralised expertise (depending on the features of the diagnostic technology itself) create the links between centres.

Adoption of a patient-held smart card would provide ready access for patients and act to spur quality initiatives, health record accuracy and public accountability. Indeed, there is good evidence from other industries that patient-facing reforms may act as a greater incentive for service improvement than an emphasis on reforming internal capabilities.

An e-health infrastructure, within which diagnostic benefits may be fully realised and which is more receptive to the health trends identified, has various components:

- A strong consumer/patient service bias,
- (Patient-held) smart cards for service and records access, authorisation and accounting,
- Ubiquity of clinical technology throughout the care pathway and across organisational and jurisdictional boundaries,
- Robots and other home-based technologies for personal care,
- Digital information infrastructure (or platform) of network-enabled technologies for remote diagnosis, treatment and treatment monitoring, and information communication technologies,
- Universal access (remote, networked) health record,
- Knowledge and skill redistribution between health professionals and involving the citizen-patient,
- Specific procurement and payment appropriate to e-health service delivery,
- Work collaboration tools to integrate distributed clinical activity.

3.7: Anticipatory Medicine And Preventative Diagnostic Imaging

There is some discussion on rethinking health prevention approaches.[145] The emergence of predictive algorithms, improved physical understanding of the determinants of disease and ill-health already point to "anticipatory medicine" with more proactive engagement with people around ways to manage personal health risks.

Preventative imaging is, controversially, proposed by some as a new approach to screening given the lack of known side-effects of MRI plus excellent accuracy. This is taken to suggest its wider use in screening, possibly replacing current screening modalities.[146]

3.8: Artificial Intelligence [AI]

The use of artificial intelligence in healthcare is increasing in interest and application.[147] It has a use in a range of areas, but three are of particular anticipated relevance.

- Image interpretation involves the use of AI for intelligent data analysis and discovery by coding in the AI software the capabilities exhibited by experts as they analyse clinical information. This is called computational modelling of cognitive processes[148] and should be seen as a precursor to "computational diagnostics".[149]

- Clinical decision support positions AI systems as *physician (or patient) assistants*, with particular anticipated capabilities in the reduction in diagnostic errors and AI-based first- and second-opinions.[150]

- Use of AI systems is also indicated in post-processing of diagnostic results, which has one effect of reducing the dependency on the skills of the operator of diagnostic equipment.[151] This would include the use of Bayesian analysis in medical imaging, already of interest.[152]

In addition, there is the predicted convergence between information and molecular technologies, with an impact on genetic algorithms, computational medicine, and biomedical informatics. Enhanced capabilities of neural networks to increase the capabilities of embedded artificial intelligence is foreseen, producing what are called 'smart technologies', involving for example robot vision to enhance the visualisation capabilities of technologies, and intelligent algorithms to interpret digital data. This last development is seen by many as the next significant generalised technological step and is currently the subject of a number of advanced research studies.[153]

3.9: Molecular- And Nano-medicine

The US National Institutes of Health describes the applications of nanotechnology for treatment, diagnosis, monitoring, and control of biological systems as "nano-medicine". Research into the rational delivery and targeting of pharmaceutical, therapeutic, and diagnostic agents is at the forefront of nano-medicine research that will open up a new horizon for diagnostic technologies.[154]

Nano-technology is expected to produce significant advances and influence clinical practice in a number of areas including drug delivery, and molecular diagnostics. This is seen as moving the focus of clinical diagnosis to the level of molecules, permitting earlier and more precise diagnosis.

3.10: The Roadmaps

The Roadmaps bring together the views in the foresight studies reviewed. They should not, though, be thought of as complete for the obvious reasons, nor the final word on potential diagnostic technology change. The Roadmaps show what a number of people have identified. Undoubtedly, upon further reflection additional capabilities can be identified, while others may be demoted to science-fiction status.

The sources for the examples in the roadmap are indicated in the tables as follows:

- European Commission: EU
- Institute for the Future: IF
- Institute for Prospective Technological Studies: IPTS
- Japanese Delphi Study: JD
- Microsoft 2020 Science: 2020
- RAND Corporation: RAND

3.10.1: New Diagnostic Capabilities

Key developments in new diagnostic capabilities are seen emerging from molecular diagnosis, the continuing development of computational capabilities (such as artificial intelligence) and nanotechnology.

DIAGRAM 3: ROADMAP FOR EMERGENCE OF NEW DIAGNOSTIC CAPABILITIES, CONTINUED					
Year 2010		**2015**		**2020**	
Ex vivo molecular-computer diagnosis: 2020					
	Computer-assisted diagnosis with pattern recognition: 2020				
	Diagnosis of kidney disorders without renal biopsy: JD				
	Advanced predictive modelling: RAND				
	Polymer-encapsulated, bioconjugated quantum dots: RAND				
		In vivo molecular-computer diagnosis: 2020			
		Self-propelled micro-machines for diagnosis and treatment: JD			
		In silico-in vivo integration (lab-on-a-chip): 2020			
		Wide deployment of non-invasive technologies and biosensors: RAND			
		In vivo visualisation of metabolism: JD			
		Diagnostic bio-chip for cancer: JD			
		Molecular imaging with single molecule precision: JD			
			Investigation of thrombosis and vascular pathology using 3D tomography with remote controlled micro-instruments: Japan, Germany, UK Foresight		

DIAGRAM 3: ROADMAP FOR EMERGENCE OF NEW DIAGNOSTIC CAPABILITIES, CONTINUED				
				Neuro-imaging at cellular level of brain processes (thoughts): 2020, JD
				Molecular-computers used to design 'smart' therapies: 2020
				Functional combination of targeting and imaging: RAND
				Automated diagnosis: IPTS
Year	**2010**	**2015**		**2020**

3.10.2: Scientific Challenges

Before a technology can be adopted, it has to be developed and that is also influenced by scientific progress in other areas. In order to realise these future diagnostic capabilities, a number of foresight studies have identified what they see as key scientific challenges where breakthroughs or developments are needed; these may be thought of as priorities for applied research. It is the use of foresight studies in this area that characterises how many countries link foresight to scientific research funding priorities.

Key amongst these is the need for progress in molecular diagnostics, continuing progress in understanding disease process, and development of computational models of disease. Machine intelligence, a promise of development probably since Alan Turing's work[155] has developed improved capabilities as computing power has increased and is central to many challenges.

DIAGRAM 4: ROADMAP FOR SCIENTIFIC CHALLENGES IN DIAGNOSIS					
Year	**2010**		**2015**		**2020**
	Molecular diagnosis: 2020				
		Identification of main disease pathways and genetic networks: 2020			
		Computational models of carcinogenesis: 2020			
		Development of effective gene therapies: JD			
			Understanding complex brain functioning: 2020		
			Emergent machine intelligence: IPTS		
			In-Silico biological models: 2020		
				Smart-drug delivery systems: IPTS	
				Predictive models of biological systems: 2020	
Year 2010			**2015**		**2020**

3.10.3: Changes In Clinical Practice

Many foresight studies identify implications for clinical practice. Both Japan and the EU prioritise a patient-accessible health record, and universal, patient-held smart card. US foresight research has proposed direct consumer access to diagnostic testing and genomic information, but this has not been seen in the other studies.

The Internet is widely discussed, with expectations of major changes arising from the promised benefits of e-health. Many studies point to increasing use of smart technologies, with home robots as a particularly provocative illustration.

The location of service delivery also changes (partly because e-health puts the point of service contact into the home) with an emphasis on remote-access health capabilities. European studies explored smarter technology becoming "ambient" -- unobtrusively embedded throughout the care process and within environments (such as home, school, workplace, transportation).

DIAGRAM 5: ROADMAP FOR CHANGES IN CLINICAL PRACTICE ARISING FROM NEW DIAGNOSTIC TECHNOLOGIES

Year	**2010**		**2015**		**2020**
	Patient-accessed, universal health record: JD, EU				
	Direct consumer access to diagnostic testing: IF				
	Diagnostic testing throughout the care pathway: IF				
		Remote internet diagnosis based on data received from patient's home: JD			
		Diagnostic-guided therapy for individualised medicine: 2020			
			Personal care nurse-robots: JD		
				Intelligent and context-sensitive clinical systems: IPTS	
				Personal access to genomic information: RAND	
Year 2010		**2015**		**2020**	

4: Strategic Options and Conclusions

This section draws the conclusions from the foresight and horizon scan literature. It also identifies strategic and policy implications as well as specific actions relevant to Ontario.

One Recommendation for further consideration and action is proposed:

There should be a systematic approach to understanding and responding to change in diagnostic technologies.

The breadth of technologies anticipated by the thoughtful research reviewed in this paper presents a challenge to how new diagnostic technologies are identified for purchase in clinical settings, how they will be used, and by whom.

The pace of technological development is rapid and in some respects accelerating, and across an increasingly broad spectrum of technologies and clinical areas. This has the potential to swamp decision-making and priority-setting bodies that may just not be able to process the necessary evidence quickly enough to meet the pace of change. This will undoubtedly require fresh insights into how we learn about, understand and make informed decisions about new technologies, how health technologies diffuse and the dynamic nature of health delivery systems themselves.

The way forward calls for a more systematic and information-rich approach to determining diagnostic capacity to meet the manifest and future population demands, how it is geographically distributed and accessed and how it is paid for. It is suggested that the scope of future developments will present particular challenge to the decision-making capacity of individual provider institutions, particularly how they address system-wide diagnostic platform requirements that transcend the interests of individual provider institutions. In the absence of a whole-system approach, individual institutions may simply fail to optimise their future technology acquisition in terms of wider system requirements.

Therefore, to deliver specific outcomes, and drive value-for-money, system-wide diagnostic capabilities, rather than specific technologies may need to be the focus of attention. An integrated diagnostic system would build upon the development of a 'diagnostic platform', comprising:

- standards (for use, interconnectivity and interoperability),
- clinical priorities and outcomes (in terms of patient-centred priorities),
- an investment and procurement strategy (to demarcate system-level strategic diagnostic capabilities from ones that can be addressed by individual providers),
- a research and development strategy (to identify gaps in knowledge, prioritise technological capabilities, and develop partnership working of health system actors, industry, R&D infrastructure and investors),
- skill and knowledge issues (to address professional roles, training) and

- public participation (to ensure the public interest is engaged).

More detailed implications are described below.

4.1: Implications For Patients And Patient Care

It is anticipated that improved accessibility to diagnostic services will emerge as easier use of diagnostic technologies, changes in user-skills and interpretive expertise, enabled in part by networking diagnostic technologies, make it possible for diagnostic technologies to be more widely distributed geographically, as well into other institutions, most notably primary care.

Patients should wait less, owing to fewer clinical encounters. In addition, it is anticipated that 'one-stop shops' (combining diagnosis and treatment) will become more commonplace.

Improved diagnostic capabilities will make earlier diagnosis possible for patients, than at present; this will be partly driven by a preference to adopt a "best technology first" policy to improve productivity and clinical outcomes.

The clinical preference toward minimally and non-invasive approaches will continue, with increasing emphasis on reducing patient discomfort arising from the features of the technology itself.

Increasing personalisation of healthcare will continue with rising patient involvement in their care, involvement in decision-making and priority setting. As well, patient knowledge will be considerably higher than at present (arising from a variety of communication media including the internet, digital interactive television) and therefore much more salient around health technologies.

4.2: Implications For Patterns Of Diagnostic Technology Use

Diagnostic processes will be less focused on technologies themselves and more on the information (from digital scanning, diagnostic algorithms, and pattern recognition) that these technologies provide, as they become ubiquitous throughout the clinical treatment process, within care pathways and at point-of-care. Convergence between this "diagnostic information chain" and electronic health records (including patient-held information on smart cards as is already the case in many countries) will enable "information guided healthcare" that occurs earlier than at present and uses 'smart' technologies with embedded artificial intelligence. This may be thought of as a paradigm shift from a service orientation on **diagnostic technology** with an emphasis on device capabilities to **diagnostic cognology** with an emphasis on information and analysis. This may have a major impact on current approaches to clinical decision-making as artificial intelligence and neural networks emerge as 'clinical assistants'.

Diagnostic processes will be more widely distributed and networked, reflecting the shift toward prioritising the cost-benefit of the value of diagnostic information and outcomes over the cost-benefit of the device technologies themselves. This will disruptively enable diagnosis to take place in more non-traditional locations (compared to today), with increasing likelihood that clinical processes will be significantly reduced by eliminating service handoffs between diagnostic and therapeutic steps.

4.3: Areas Of Most Potential For Future Innovation

Disruptive technologies are emergent in these areas:

- Molecular medicine, with the development of 'molecular computers', are expected to operate at the genetic and molecular levels to detect disease precursors;
- Nano-technology is expected to produce potentially disruptive developments within the next few years;
- Optical methods, including infra-red, spectroscopy and bioluminescence, are emerging diagnostic technology as they offer improved resolution over the limits of currently favoured technologies; with improved resolution comes the ability to diagnose earlier.

Emerging technologies that are already being prototyped exemplify potential clinical advantages and patient benefits. In many cases, the clinical applications are a technology transfer from other technologies or areas of scientific interest.

TABLE 17: IMPACT OF TYPES OF EMERGING DIAGNOSTIC TECHNOLOGIES, CONTINUED

Reduced Costs	PETRRA is a PET with the capability of imaging 40 cm sections versus the current 16 cm. There is a claimed cost reduction (to perhaps half current levels). This is an example of technology transfer, in this case from the detection chambers used in particle physics.
Smaller	A hand-held gamma camera is currently in development, with sub-millimetre resolution. This is an example of technology transfer from x-ray astronomy.
Remote Use	A portable hand-held robotic ultrasound device, which permits non-specialists to produce safe and reliable echographic diagnoses, an e-health diagnostic technology, utilised over a digital network.
Non-invasive	Non-invasive diagnostic procedures are being developed to exploit digital modelling of data, e.g. virtual colonoscopy, a further development of computed tomography.
Innovative	Novel developments are often triggered by capabilities in other fields, hence the emphasis on the examples of technology transfers and building interdisciplinary activities. The Electronic Nose is an example of olfactory sensors to detect odours linked to specific disease conditions, mimicking the detection abilities of dogs.

TABLE 17: IMPACT OF TYPES OF EMERGING DIAGNOSTIC TECHNOLOGIES, CONTINUED	
Potentially disruptive	Molecular diagnostics is an area of considerable interest, with specific predictions of *ex vivo* and *in vivo* molecular computers specifically for diagnosis. In time, molecular computers will underpin 'smart' therapies, which involve embedding artificial intelligence within the diagnostic processes themselves. Bio-conjugated quantum dots, which are of considerable clinical interest as they can bond to specific biological molecules within cells, underpin the possibility of molecular and cellular imaging, to detect molecular signatures that are predictive of, for example, cancers. There is some speculation that neuro-imaging will develop to the point of imaging at the cellular level to create visual images of thoughts to aid diagnosis.
Disruptive	Artificial intelligence [AI] is viewed favourably in many areas, with expectations that advances in predictive modelling of health/disease conditions will prove productive as there is a well-established research agenda on machine intelligence. The expanding role of AI will track the development of cognitive models of clinical reasoning and physical (deterministic) models of disease. AI and neural networks in healthcare are still at an early stage, but improved diagnostic outcomes are seen from efforts to link robotic vision with pattern recognition for computer assisted diagnosis.
Patient focus	Future developments such as these are seen as precursors for 'individualised' medicine, based on developing causal and computational models of individual responses to treatment, rather than on epidemiological models, with their focus on populations.

4.4: Clinical Areas Most And Least Likely To Benefit

The emphasis on information-guided treatment will have an impact on areas of clinical activity that use diagnostic information. This will have both positive and negative implications, particularly for the demarcation of professional spheres of knowledge and responsibility. Information will flow more easily through health systems and be more readily available to all those who may require it when they need it, including the patient.

Clinical activities, which may delay clinical processes, should become less so; indeed, later staged technologies that produce superior results are more likely to be used earlier as the 'best technologies first' approach offers improved system-level productivity gains and improved clinical outcomes.

Increased computer power means that real-time (4D) processes will be the norm. The impact may be most pronounced in neuro-imaging with deep insights into the nature of the brain and brain dysfunction, and improved understanding of the determinants of mental ill-health.

Molecules are becoming the focus of diagnostic interest with the ability to detect disease precursors earlier.

Invasive diagnostic procedures will become less necessary as understanding of information gathered from molecular computers and image-based technologies produces comparable information.

It has not been determined whether current concerns at rising whole population radiation doses (largely arising from increased use of CT) will cause further scientific or public concern and cause a shift toward technologies that do not use X-rays.

4.5: Implications For Skill Mix, Clinical Roles, Service And System Integration, Innovation

As diagnostic technology becomes easier to use and the results more accessible to non-specialists, the professional role demarcations between individuals who operate equipment, who interpret the results and who act on the information provided will become less significant. The effect will be to favour the end-user closest to the patient and who will combine all of these roles. There will be fewer hand-offs of clinical information between individual specialists or between service provider organisations. The effect is to integrate diagnosis with the treatment process. This will have the further effect of blurring what are at present defined boundaries between health professionals; it should be anticipated, for instance, that some skill and knowledge will shift from radiologists to physicians and surgeons. As newer technologies may require less specialist skills to operate, there will be challenges to the role of technicians who operate diagnostic technology.

The potential of new diagnostic technology to end up in primary care and non-traditional settings is a possibility. The effect of technologies becoming easier to interpret and their use in remote locations define the e-health impact to decentralise some aspects of diagnostic roles to other levels of skills and knowledge. In particular, the ability of some diagnostic technologies to be used by lay individuals (e.g. in the home) with results being interpreted either locally through 'embedded intelligence' or remotely by a specialist in a central location, has the effect of altering the service delivery role of centralised diagnostic centres. Access to the expertise to interpret the results will become more important than physical access to the technology itself.

A networked and distributed health service delivery system challenges the logic of skill aggregation that defines the hospital. However, this impact is not well understood. Generally, the trend of technologies as they mature is toward simplification and wide distribution with a corresponding impact on operator knowledge. healthcare has traditionally depended on centralised knowledge within hospitals, but greater technological diffusion in primary care and non-traditional settings has implications for this model.

The innovative combination of diagnostic technologies with therapeutic interventions (e.g. interventional radiology, integrated therapy systems) offers the possibility of an increasing number of clinical work settings to be structured as "one-stop shops" for rapid diagnosis and treatment.

New technologies do not always reduce costs; rather, they tend to offer greater treatment options and thus increase demand for service. However, emerging diagnostic technologies offer benefits to achieve productivity gains and better value for money as they simplify clinical work processes, yield improved patient outcomes, or enable one-stop diagnosis/treatment. The effect may be to provide improved sustainability in the face of rising demand by embedding diagnosis within a more integrated delivery system, through for example integrated care pathways.

4.6: Strategic And Policy Implications For Ontario

A more managed approach to technology introduction would permit earlier assessment of technologies to aid planning and priority-setting.

Technology investment may act as an economic driver with benefits for the whole health system, an approach that other countries are exploring, with medical technologies having been identified in some jurisdictions as a priority. Having a well-developed and highly motivated research and development infrastructure in Canada presents Ontario with intriguing opportunities to explore how investing in new diagnostic technologies can benefit patients, as well as bring wider economic and productivity gains to the health system, with the potential to release resources for reinvestment in other areas of healthcare. Being an earlier adopter of new technologies has immediate implications for the scope of health technology assessment, with the possibility that outcomes and benefits can be realised sooner, while the disbenefits of immature or ineffective technologies can be identified sooner.

There is potential disruption to the work of clinical professionals, and the blurring of roles between technologists, medical specialities and primary care providers and the potential to increasingly involve patients in their own care. This suggests that the educational needs of future health professionals will be affected.

The decentralisation of the health system through the LHINs, highlights the potential impact of technological change on the mandate of LHINs when they consider diagnostic services. LHINs have the opportunity to leverage these potential technological changes to enable non-traditional, but potentially disruptive, forms of provision, including in patients' homes. The disintermediation of clinical processes, that move clinical service delivery to providers closer to patients, or the integration of clinical processes into one-stop patient encounters have important implications for service configuration.

The role of health technology assessment is a major factor in making sense of the foresight and scan research. Ontario's existing commitment to world-class technology assessment of existing technology could be augmented by similar leadership in 'future-oriented technology assessment'.

Public interest in health system priority setting is increasing with rising public understanding of healthcare technologies. Ontarians are interested in these technologies, and their impact on their potential future healthcare. The public will also be interested if these technologies lead to new integrated forms of provision in their homes.

4.7: Implications For The Assessment Of Health Technologies

Implications for health technology assessment lie in four areas:

- Building foresight capabilities improves anticipatory capacity for decision- and policy-making as technological changes happen faster than our assessment systems can respond.
- Benefits realisation of future technology becomes critical to realise value-for-money within technology planning and procurement.
- Assessing the impact of diagnostic technological change on society reflects changing society values, as new technologies also offer new thinking on treatment, and identifies new priorities for expenditure.

- Obsolescence oversight, and providing guidance on technologies in decline.

4.7.1: Building Foresight Capabilities

The lessons from other jurisdictions show that foresight exercises and scanning are a crucial but evolving tool to better anticipate the impact of new science and technology. The current focus and priority within the province and most jurisdictions is on technology assessment, with a time horizon of generally less than 2 years.

It would be productive, though, for technology assessment to have a longer time horizon. This might include a focus on "science assessment" to capture the potential implications of new scientific findings, and thereby bring a broader perspective to assessment.

The overall objective is to better assess technological impact. Some countries have an 'early adopter' policy to encourage earlier identification of benefits. This is normally integral to some type of technology policy. Earlier adoption enables earlier understanding of patient impact and clinical practice to inform the evidence base on the efficacy of the technology itself. Such a policy, though, will have implications for the role of health technology assessment in the case of prioritised technologies.

The main area where foresight studies become murky is in assessing likely diffusion and uptake, as diffusion is in part influenced by the outcomes of technology assessment.

To improve assessment of future technologies, we will need to understand how

- to better align the various diagnostic modalities with their optimal use, and

- to assess diagnostic equivalence between competing methods.

MRI[156 157] has been largely suboptimal in assessing articular cartilage, for instance, but it is seen as the optimal diagnostic tool because of its superior resolution. A decade earlier, in 1994, research had suggested that MRI offered great promise, but was undefined as a clinical tool. Other clinical and diagnostic disciplines reported similar views when looking at future use.[158 159] Care must be taken, therefore, in assessing potential benefits/disbenefits, or the time frames for new technologies to emerge, as they can be highly incentivised by demands from clinicians and other market forces. For instance, the *appearance* of diagnostic images, where images are colour-coded,[160] identifies colour representation as a source of diagnostic error.[161] Failure on the colour side will only undermine the diagnostic equivalence of competing display methods especially as digital images are replacing film.[162] The trend toward digital image representation itself must add clinical value, but it must also ensure fidelity of the image content itself. Therefore, the value of digital images in future technology will need to be virtually equivalent to images seen directly.[163]

As our understanding of health system performance becomes more evidence-informed, health technology assessments of future technologies will become more important. It should certainly continue to be undertaken in advance of commercial availability but it may need to embrace a wider 'socio-economic' dimension to reflect actual use of these technologies. Findings here will in turn influence adoption and diffusion, and in turn investment and research priorities, and what becomes available to the health system.

The risk is that a 'medico-industrial' complex turns this cycle of development into a mutual dependency, where technologies create new needs and expectations, which in turn drive new technological development, without breaking the cycle with evidence of real need and clinical efficacy.

4.7.2: Benefits Realisation Of Future Diagnostic Technologies

Future healthcare will benefit from current learning about healthcare systems as complex adaptive systems.[164] Healthcare systems cannot sensibly be separated from other aspects of social and economic life; health systems will, therefore, continue to attract wide interest across all of society. Understanding this complexity, though, is a challenge.

The Canadian federal government, for example, has identified a number of concerns with the evolution of the Canadian healthcare system reflecting differences between provinces. The federal government notes: "… barriers have been created in Canadian healthcare due to fragmented and parochial approaches to procurement of diagnostic imaging and information technologies."[165] This fragmentation also means that while Canada is a major contributor to international understanding in health science, provinces have not always learned how to exploit this for service delivery and investment. Fragmentation also means that the potential social and economic benefits of new technologies may not benefit all Canadians equally.

The smaller scale of provincial healthcare systems makes fruitful partnerships between industry and academe less productive when compared to the scale of competitors such as Germany, UK, Japan or the US. The consequence is to make many smaller health systems (not just in Canada but around the world) net consumers of novel diagnostic technologies, and late adopters of these innovations, particularly when compared to how other countries move to exploit scientific developments through to commercialisation.

Ontario, however, benefits from a world-class scientific, commercial and academic infrastructure which does offer opportunities to create a virtuous cycle of research, experimentation, prototyping and commercialisation. Medical technology clusters in London and Toronto offer considerable potential, while the information technology cluster in Waterloo can exploit the increasing role of communication systems to diagnostics.

With future implementation of an e-health infrastructure, additional patient benefits and economies of scale may be realised which would exploit these system capabilities. E-health offers the opportunity to separate geographically the diagnostic technologies from the expertise to interpret results, particularly as future technologies are likely to require less technical expertise to use, and will be portable or hand-held,; in addition, with digital technologies, network readiness is a given.

Economic factors influence health technology assessments and investment decisions by many actors who fund technological research and development, in particular at the early stage where the risks are greatest. Government policies have a key role in the healthcare reimbursement decisions, in procurement of new medical technologies, and overseeing implementation of health technology assessments. These policies affect how ideas are converted into product reimbursement practices have been shown to be an influence in adoption and diffusion.[166]

Future social influences will arise from patient expectations of healthcare technology and public attitudes toward new technologies. Future knowledge-based influences will depend on the state of academic and corporate research. Access to appropriate funding (for research, development, and venture capital) determines what ideas and innovations are pursued and therefore in what directions new knowledge will be developed.

The ability of research units (whether academic, corporate, or private) to organise themselves to undertake world-class and innovative research is a factor favouring well-organised research institutions over less well-developed ones. High quality researchers and innovators migrate to places (universities, companies, countries) that facilitate their knowledge work. And patterns of knowledge utilisation play into the knowledge value chain by favouring some innovations over others.

The benefits from future diagnostic technologies will favour those technologies that diffuse, and that in part is a function of a market created by early adopters providing evidence of usefulness. This creates a tension with health technology assessments that attempt to determine the benefits of innovations, something early adopters are keenly interested in determining but in a different way.

However, much depends on the future actions of those countries that prioritise medical and diagnostic technologies. Ontario may find itself dependent on the commercial and research priorities of other countries and that will determine how it meets domestic priorities. The alternative is to development a research and development pipeline that is amenable to influence through public policy. [167]

4.7.3: Assessing The Social Impact Of Technological Change[168]

Technology as is well known brings with it serious ethical dilemmas; fire from the gods was just the first. All scientific advances bring their own tests of our humanity, and perhaps these are particularly powerful tests in medicine, where through the very best intentions, clinicians seek, by doing no harm, to do the most they can for the health of their patients.

The dilemma for medicine is deciding when technologies are prolonging life, and when they are delaying death. While health technology assessments of necessity need to use some quantitative cut-off, perhaps a QALY (quality-adjusted life-year) measure, these are economic measures, and may not in fact measure the moral calculus that society would use. In that respect, we can never be certain, only reasonably confident that we fully understand the value of new diagnostic technologies in a social context; but as rational beings, we should always be prepared to change our mind.[169]

Overlaying, therefore, the foresight work is a needed understanding of what impact new diagnostic technologies have on how society itself views healthcare, in particular, where the treatment options are less robust than our diagnostic capabilities. Technological change does not occur evenly, so there is no reason to assume that advances in diagnosis are coupled with corresponding advances in treatment. They are separate but connected and the extent to which they are disconnected is of considerable social as well as scientific interest. Related to this is a view that technology will develop in the next few years to support rational decision-making by incorporating scientific knowledge, and value judgements in an "organised and analytical manner".[170]

For many, this dilemma captures a fundamental ethical concern of when there is too much medicine. As scientists push the boundaries of our understanding of the world, and increasingly that understand is applied to human health, we will find at some point a need to re-affirm the essentials of what it means to be human. Are patients like a geological feature, to be mined using a variety of tools to see what might be there, just in case? And will patients permit themselves to be treated in this way?

4.7.4: Obsolescence Oversight

While the foresight and scan research lacked consensus on technologies that will become obsolete, some trends are clear in what might drive changes in the technology utilisation cycle.

Changes in technologies appear to be happening quicker -- a robust investment climate coupled with an appropriate reimbursement regime implicates quicker development. Since development of most diagnostic technologies is incremental, with subsequent changes building on earlier approaches, looking for step-change improvements may not be helpful. At what stage in an incremental development process does a technology become obsolete? This presents health systems with the difficult decision of determining at what point new technologies offer substantial clinical benefits, and indeed when a technology should be phased out of use. Decisions may need to be taken independently of the claims of manufacturers or indeed demand for the technology by clinicians, to assert continuing clinical efficacy.

The leading edge of what might constitute a systematic approach to technology replacement would need to take account of what we know from existing technology assessments, plus anticipate the potential clinical benefit of emerging technologies but without the merit of a robust evidence base. Technology assessment processes may already be slow compared to pace of technological change and innovation, raising the spectre that technologies may evolve faster than decision-making on adoption and use.

The policy of using the 'best technology first' to achieve better patient outcomes suggests a replacement strategy for new technologies, but it depends on whether the new and emerging technologies actually produce the anticipated integrated diagnostic/therapeutic benefits, and whether the redistribution of expertise and technology actually improves access.

However, this strategy would be compatible with the outcomes of a planned diagnostic system with identified priority outcomes, and not ad hoc decisions of decentralised providers.

4.8: Implications Of Technological Change On Costs Of Technology And Productivity

Despite suggestions that some emerging technologies will be cheaper than what is currently available, one cannot assess the future costs of technology meaningfully; nevertheless, there are potential downward cost implications from the technology trends:

- Emerging technologies will combine features of other technologies, so called hybrid technologies that may offer different cost models when compared to their separate components;

- Emerging technologies in many cases will be smaller, safer, faster and smarter, which may revise current assumptions of cost drivers, as new technologies are more productive, require

less specialist expertise to use or interpret results, produce results quicker, and are integrated into care pathways;

- "Best technology first" is an approach to thinking about the role of new technologies, that offer quicker and often one-stop diagnostic encounters, and use a different approach by costing the technology in terms of patient outcomes and productivity;

- Skill mix issues have been encountered: office-based diagnostic technologies being used and interpreted by the physician, or specialist hybrid technologies interpreted by cardiologists or oncologists, supplanting the role of the radiologist.

Developments toward hand-held devices, cheaper PETs, and other applications point to reduced scale and lower costs as today's large and expensive devices become small, and portable.

Many studies cited potential improved productivity and this has been a recurring theme through the foresight and scan literature, when measuring clinical workload or when integrating diagnosis with other technologies. These potential sources of cost and benefit suggest that taking a more systems view would leverage additional gains when measured in terms of patient outcomes.

The possibilities of e-health-enabled diagnostic technologies offer system-wide economies of scale as the cost of the technology and where it is located are determined independently of the costs of the expertise to interpret the results. The current level of e-health understanding is largely built on pilot projects and does not reflect real-world patterns of use or cost.

Artificial intelligence offers cost benefits by reducing reliance on higher cost clinical intermediaries (either health professionals or institutional settings), by shifting expertise either toward the patient through self-care, or toward the clinical end-user, and toward single-location care delivery.

The absence of a system-based approach to technology procurement means that cost efficiencies of a diagnostic platform are not recovered. Ontario is a single purchaser of some health technologies, but there is little harmonisation of technology acquisition practices across Canada. As well, Ontario is at or below the Canadian average for diffusion of diagnostic technologies.[171]

4.9: Next Steps For Ontario

While responding to technological change is not new, as all technologies bring both benefits and disbenefits, the emerging features of new diagnostic technologies suggest that leadership is needed. This has specific meaning in Ontario.

There is potential disruption to the work of clinical professionals, and the blurring of roles between technologists, medical specialities and primary care providers and the potential to involve patients in their own care. This suggests that the education of future health professionals needs to be addressed with some urgency, as the pace of technological change appears to be faster than curriculum reform. We are likely to see early changes in the sophistication in diagnostic computer algorithms, for instance, as well as technologies that will empower patients. It is worth keeping in mind that many of the anticipated impact will be within 5 years, suggesting some relevancy for current training priorities.

The decentralisation of the health system through the Local Health Integration Networks [LHINs] in Ontario, highlights the potential impact of technological change on the responsibilities of LHINs when they consider diagnostic services. Quite apart from the issue of technology procurement and economies of scale, the potential impact that networked and decentralising technologies can have on legacy provider arrangements needs careful review. For instance, the possibility of a provincial diagnostic platform of networked diagnostic technologies anchored in e.g. smaller care providers would cross LHIN boundaries. In addition, LHINs have the opportunity to leverage these potential technological changes to enable non-traditional, but potentially disruptive, forms of provision, including into patients' homes. More widely, the disintermediating of clinical processes, that move clinical service delivery to providers closer to patients, or the integrating of clinical processes into single one-stop patient encounters have important implications for service configuration. These are the responsibilities of LHINs, whereas the implications of poorly coordinated diagnostic service planning by LHINs will have provincial impact.

Having a well-developed and highly motivated research and development infrastructure in Canada presents Ontario with intriguing opportunities to explore how investing in new diagnostic technologies can benefit patients, as well as bring wider economic and productivity gains to the health system, with resource releasing potential. Being an earlier adopter of new technologies has immediate implications for the scope of health technology assessment, with potential benefit as the gains are realised sooner while the disbenefits of immature or ineffective technologies are identified more quickly.

The role of health technology assessment is a major factor in making sense of the foresight and scan research. Ontario's existing commitment to world-class technology assessments of existing technology could be augmented by similar leadership in 'future-oriented technology assessment'.

Whether at the LHIN or provincial level, public interest in health system priority setting, particularly around diagnostic technologies is increasing. Ontarians will be interested to know about these technologies, and their impact on their potential future healthcare. The public will also be interested if these technologies lead to new integrated forms of provision, and whether some of these capabilities will reside in their homes.

Finally, provincial leadership is relevant to establishing the public's understanding of system planning around on the adoption of new diagnostic technologies, and overall accountability for system coherence to avoid differential diagnostic outcomes across the LHINs.

5: Appendix: The Medical Technology Industry

Ever since Stanford University and Hewlett-Packard agreed to collaborate in Palo Alto, California, researchers have tried to understand how the success of what became Silicon Valley could be replicated in other countries. Other countries have viewed Silicon Valley's successes with considerable envy as the innovations there turned into economic power and in some cases dominated specific industries.

Silicon Valley benefited from three key virtues: [172]

- a ready supply of capital to fund the development and research,
- a ready supply of highly motivated knowledgeable individuals flowing between academe and industry,
- active encouragement by the local government in respect of planning and regulation.

Success in other countries has faltered in many instances as rigidities in the academic or labour markets frustrated efforts to innovate, or local governments complicated plans to develop research facilities. For many countries, the local capital markets were risk averse or unable to fund the level of capital to realise the necessary benefits. Finally, the ability of healthcare systems to absorb technological innovation limited commercialisation. The overwhelming design logic, though, correctly identified clustering as a key factor in generating innovations worth funding, and clusters have proliferated, but not always successfully.

The WHO's Commission on Macroeconomics and Health,[173] while focusing on the investment needs of less well-developed systems, did serve to raise an alternative perspective on healthcare expenditures. This has stimulated a rethink of the way that many higher-income companies view health system expenditures. More recently, the European Commission commissioned a study of the subject of health system investment with a focus on high-income countries.[174] Variations between countries and regions, of course, complicate easy comparative lessons, but a compelling case is France, where the failure of innovative industries has been described as a cause of the country slipping behind its European Union peer-group, and where public policy since at least the mid-1990s has unsuccessfully tried to create an appropriate climate for innovation and development.[175]

Key benefits accrue from research clusters, in terms of wealth creation from high-wage and high-profit industries working in research and development collaboration with other knowledge creation industries, such as private research laboratories and universities.[176] It is also important to understand that advanced technology industries such as those that produce diagnostic technologies do not organise themselves like traditional industries. They are critically dependent on access to uniquely skilled people, and to information, [177] and so rely less on traditional incentives such as large pools of traditionally skilled labour, rail and road links and water – compared to the automobile industry. As well, there is some evidence that the most desirable employees for high-technology employers may also have very strong ties to their universities or research facilities, which further emphasises the need to ensure fluidity of movement between academe/research and industry. In addition, many technology firms are increasingly spin-offs from university research, and certainly within Canada, there have emerged a few 'breeder' universities with sizeable numbers of spin-off companies, all of which locate within the general

geography of the breeder site, creating further demand on the locality and feeding what many hope is a virtuous cycle of further research and development.

Countries that are concerned about the links between public policy and high-technology innovation include the US, the European Union, the UK, Germany, Japan, and China.

In the case of the European Union, the pharmaceutical industry is viewed as a strategic industry,[178] a view which is shared by the key European countries with large biotechnology industries, specifically, the UK and Germany. Germany, in particular, has moved to strategically position the medical device industry.[179] Japan maintains a continuing brief on technological change with a focus on performance comparison to the US and the EU.

The US dominates the global device market of US$165 billion in 2003, of which global revenues of US$135 billion went to US companies.[180] The other, but smaller, key device countries are the UK, Germany and Japan. Canada is the seventh largest medical technology consumption market (at US$3.4 billion) but is largely served by imports from the US and does not supply itself.[181]

Burns assesses key factors for US dominance in healthcare innovation as these:[182]

- a more specialist-dominated medical profession,
- more sophisticated and supportive clinical infrastructure,
- higher consumer demand for innovative products,
- a reimbursement system that permits access to innovative technologies,
- the general absence of government rationing in healthcare,
- the profit motive, and
- lacking the impediments and rigidities in European and Asian countries that hamper innovation.

5.1: Medical Technology In Canada

In Canada, the federal government has observed that national performance in innovation has been declining, with GDP expenditure on R&D declining from 2.05% in 2001 to 1.89% in 2004. Canada underperforms when compared to its G7 peer group.[183] [184] Yet, technology companies, taking a whole-industry perspective, account for 15% of the Canadian economy and more than 30% of current exports.[185]

Technology clusters have emerged as important in moving technologies from research novelty to practical tool.[186] The National Research Council has established a Life Sciences/Medical Devices technology cluster in Winnipeg,[187] this despite the sustaining environments with the most appropriate research infrastructures being located elsewhere in Canada. Ontario benefits from an NRC photonic facility, co-located with the Ottawa-Kanata *Techopia* for information technologies. Ontario is also the key source of venture capital in Canada, and has the largest and best-developed medical research infrastructure in Canada. It has a major technology cluster in

Waterloo-Kitchener-Cambridge[188] anchored around the University of Waterloo.[189] Indeed, the relationship between the University of Waterloo and Research in Motion [RIM], the corporate developers of the Blackberry, is reminiscent of the early stages of Silicon Valley. Given the technology trends involving computer technologies, this cluster may be particularly well-positioned for the future.

The biotechnology cluster, anchored around Montreal, is developing into nano-technology and related medical device technologies, and currently is second only to the US for biotechnology companies, anchored by McGill, the Université de Montréal and Laval. Québec has attracted many diagnostic and technology companies which have developed productive relationships with the universities of Montréal and Laval. A similar cluster exists in British Columbia.

Ontario has already seen the need to encourage medical technology clusters with funding for the Ontario Rehabilitation Technology Consortium, which played a leading role in developing this type of technology in the province. The work has now been taken over by the Health Technology Exchange. No information on its effectiveness has been obtained.

Current provincial initiatives include the MaRS Discovery District in Toronto and offer an opportunity to encourage technology developments within this evolving convergence facility. As well, the Perimeter Institute for Theoretical Physics at the University of Waterloo (endowed by the founder of RIM), could anchor a scientific cluster, with a potential to conduct advanced physics research, which has proved so effective in advancing imaging technology developments to date. Two key centres already exist in Ontario, one in Toronto and one in London, and anchor significant work.

In addition, the United States, which controls the majority of the global market in diagnostic technologies has a number of research centres advancing the field. European centres are centred in the UK and Germany. Japan is an important centre, with China rapidly developing capabilities. These countries see the future of medicine is becoming one of a partnership amongst doctors, physicists, chemists, and others, working together productively.[190]

5.2: Medical Technology In Ontario

There are 101 diagnostic companies of a total 633 medical and assistive device companies in the province, and …

- of the 633 companies, 74% are Canadian owned
- 59% of the companies were created after 1981
- 71% have sales of less than C$10 million, with no company having over C$350 million in annual sales
- Ontario has developed specific expertise in medical imaging, with several centres demonstrating leadership. These include:
    - Imaging Network Ontario, anchored at Sunnybrook and Women's College and the John P Robarts Research Institute, London, funded by the Ontario Research and Development Challenge Fund

- BRAIN is a research collaboration of 12 centres, anchored at Rotman Research Institute (Baycrest Centre for Geriatric Care, Toronto)
- Ontario Centre for Excellence in Breast Cancer Imaging, centred at Sunnybrook/Women's College
- Ontario Consortium for Image-guided Therapy and Surgery, managed by University Health Network
- Centre for Vascular Imaging, at the John P. Robarts Research Institute, London
- Ontario Consortium for Cardiac Imaging, centred at Sunnybrook/Women's College.

Additional expertise in biocompatible materials exists at the University of Toronto's Institute of Biomaterials and Biomedical Engineering, rated within the top five such centres in the world.

Ontario's medical and assistive device capabilities are seen as being anchored by 5 world-class academic health science centres at McMaster, Queen's, Western, Ottawa and Toronto.[191] More generally, Ottawa, Kingston, Toronto, York Region, Mississauga, Hamilton/Niagara, London are seen as provincially significant centres.

5.3: Significant Technology Clusters In Canada

Apart from centres with provincial significance, Ontario contributes three nationally recognised centres in diagnostics:

- Information technologies: Kanata/Ottawa, "*Techopia*"
- Mixed Technology : Kitchener-Waterloo-Cambridge, "*Technology Triangle*"
- Biotechnology: Montreal/Quebec, "*Biotechnology Gateway*"

There are two nationally comparable centres, both in Alberta:

- Biodiagnostics and micro-devices
- Digital imaging/computer vision.

The National Research Council funds a medical device research centre in Winnipeg with an emphasis on medical imaging.

5.4: Technology Commercialisation

Ontario, like some other provinces, notably Alberta, have encouraged policy and investment to commercialise medical research:

- Ontario Health Technology Exchange
- Alberta Heritage Foundation for Medical Research commercialisation programme.

6: Appendix: Methodology

Research was obtained from a number of sources. These included internet searches, PubMed searches, various provincial and federal government and technology assessment reports, and data from health agencies including those from the Ministry of Health and Long-Term Care, the Institute for Clinical Evaluative Sciences, and the Canadian Institute for Health Information, as well as groups in Europe, the US and elsewhere.

A PubMed search was conducted for review articles reporting on the current and future development of medical diagnostic technologies published in 2005/2006. Articles describing the current state of the technologies, their future trends in technical advancement, related clinical studies, critics' reviews of their advantages and disadvantages on clinical applications and potential use by various jurisdictions were reviewed.

The objectives of the literature scan were to:

- identify and classify different types of diagnostic technology development over the next few years,
- identify the most significant drivers of technological change,
- determine as best as possible the stage of development and potential for availability and likely diffusion,
- identify the potential impact in Ontario.

In assessing technologies that fail the key test of being about to be launched onto the market, it is more difficult to discern how these technologies should be assessed. Foresight participants have arrived at a working definition to guide assessment, namely:

- Technology that has not been adopted (i.e. accepted as a standard technology) by a healthcare system;
- Technologies that are currently available but still evolving;
- Technologies for which a strong body of evaluative research is unlikely to be available;
- Technologies that have not been launched or marketed.[192]

7: Appendix: Glossary of terms

New and emerging technologies

- Technologies which are currently available but still evolving
- Technologies for which a strong body of evaluative research is unlikely to be available
- Technologies which have not been launched or marketed

Incremental technology: definition (also called "sustaining technology") [193]

- successive incremental improvements in current performance that stakeholders can incorporate into existing technologies

Disruptive technology

- break existing rules of practice
- disintermediate supply change
- integrated or removed steps in a clinical process
- cheaper, simpler or more convenient to use
- overthrow existing technologies

Arthrography – MRI

An imaging study designed to diagnose problems within a joint (e.g., shoulder, hip, and wrist) with the aid of a contrast agent called gadolinium. When this contrast agent is introduced into the joint, it enhances the visualization of joint structures and improves MRI evaluation of joint abnormalities

Bone Scan

A nuclear medicine bone scan, also called Bone Scintigraphy, provides information that shows how bone cells are performing—whether normally or abnormally, and to what degree. It is used to find bone and joint problems such as cancer, infections, fractures and arthritis

Colonography

A Virtual Colonoscopy or colon scan evaluates the colon for polyps and early colon cancer. Performed using a CT Scanner, the virtual colonoscopy reveals areas that may be unseen with other diagnostic techniques.

Computed Tomography (CT or "CAT" Scan)

The scanning procedure is a diagnostic examination that combines x-rays and computers. CT scanning reveals structural information of organs (such as the pancreas, intestines, kidneys, lungs, and heart), blood vessels, the abdominal cavity, bones, and the spinal cord.

DEXA

Dual Energy X-ray Absorptiometry is a test for measuring bone mineral density. The scan is a reliable test to determine early stages of bone loss associated with osteoporosis.

Magnetic Resonance Imaging (MRI)

It is an imaging technique that combines a powerful magnet with an advanced computer system and radio waves to produce accurate, detailed pictures of organs and tissues to diagnose a variety of medical conditions.

Mammography

It uses a low-dose x-ray to facilitate early detections of breast cancer. Mammography can also be performed using Ultrasound and MRI procedures.

Multi-Gated Cardiac Scan (MUGA Scan)

A nuclear medicine MUGA scan is used to examine the size, wall motion and function of the heart.

Myelography

It is a diagnostic procedure performed on the spinal cord and/or nerves, and involves injecting a contrast agent (x-ray dye) into the spinal canal. Myelograms are usually done to evaluate for disc herniation, stenosis, bone spurs or arachnoiditis.

Myocardial Perfusion Imaging

It involves the use of radioactive materials, Technicium^{99} and Thallium, to check the flow of blood to normal and diseased tissues.

Nuclear Medicine

Nuclear Medicine is well known for imaging bones and joints to detect a number of abnormalities including trauma, fractures, arthritis or tumours. It differs from other diagnostic procedures like CT, MRI, or x-ray as it images organ function, rather than just the anatomy. The procedures monitor cancer, but also study the activity of many organs including the thyroid, heart, stomach and kidneys.

Optical Coherence Tomography

Optical coherence tomography (OCT) is a rapidly emerging technology for high-resolution biomedical imaging.

PET/CT Scan

It simultaneously images and combines the results of two scanner technologies into a single examination. The highly sensitive PET scan picks up actively growing cancer cells, and the CT scan reveals the size and shape of abnormal cancerous growths. At this time, PET/CT is one of the most powerful tools in cancer diagnosis and staging.

Ultrasound

This diagnostic procedure bounces high-frequency sound waves off parts of the body and captures the returning "echoes" as images. Ultrasound is able to capture moving images of pelvic and abdominal function (including gallstones), breast abnormalities, the male reproductive system, the kidney and thyroid systems, as well as the developing foetus. When enhanced with a special Doppler technique, ultrasound can also capture moving blood images of large blood vessels and moving images of the heart using echocardiography.

X-ray, or Radiography

It refers to procedures that use standard x-rays to view parts of the body. They include common x-ray, tomography, and fluoroscopy.

Semiconductor quantum dots

Have the potential to become a new class of fluorescent bioprobes for many biological applications and imaging.

8: Appendix: Selected Web Resources on Technology Foresight

Battelle	http://www.battelle.org/forecasts/default.stm
Canada: Canadian Agency for Drugs and Technologies in Health	http://www.cadth.ca/index.php/en/home
Canada: Canadian BioStrategy	http://www.biostrategy.gc.ca/english/view.asp?x=521
Canada: Federal Science and Technology	http://innovation.gc.ca/gol/innovation/site.nsf/en/in05245.html#forpara
Canada: Industry Canada Technology Roadmaps	http://strategis.ic.gc.ca/epic/internet/intrm-crt.nsf/en/home
Canada: Medical Imaging Foresight	http://strategis.ic.gc.ca/epic/internet/inmitr-crtim.nsf/en/Home
Canada: National Research Council	http://www.nrc-cnrc.gc.ca/aboutUs/ren/nrc-foresight_1_e.html
Canada: National Science Advisory, Office of Science and Technology Foresight	http://science.pco-bcp.gc.ca/default.asp?Language=E&Page=Home
Center for Technology Roadmapping, Purdue University	http://roadmap.itap.purdue.edu/ctr/default.htm
European Commission: Foresight	http://cordis.europa.eu/foresight/kte_expert_group_2005.htm
European Commission: Institute for Prospective Technological Studies	http://www.jrc.es/home/index.htm
Germany: Fraunhofer Institut System- und Innovationsforschung	http://www.isi.fhg.de/homeisi.htm
Institute for Alternative Futures	http://www.altfutures.com
Institute for the Future	http://www.iftf.org/

Ireland: Foresight	http://www.forfas.ie/icsti/statements/tforesight/overview/tforeire.htm
Journal: International Journal of Forecasting	http://www.elsevier.com/wps/find/journaldescription.cws_home/505555/description#description
Journal: Technology in Society	http://www.elsevier.com/wps/find/journaldescription.cws_home/384/description#description
Journal: Technovation	http://www.elsevier.com/wps/find/journaldescription.cws_home/422925/description#description
Ontario: BioOntario	http://www.bioontario.ca/
UK: Foresight	http://www.foresight.gov.uk/
UNIDO: International Materials Assessment and Application Centre	http://200.20.105.7/imaac/techforesight.html
US: BlueCross BlueShield Association Technology Evaluation Centre	http://www.bcbs.com/tec/whatistec.html
World Technology Assessment Center	http://www.wtec.org/

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